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LEVEL II

# ENGINEERING AND DEVELOPMENT PROGRAM PLAN

# AIRCRAFT CABIN FIRE SAFETY

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JUNE 1980

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Director, Federal Aviation Administration Technical Center

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16. Abstract

The Aircraft Cabin Fire Safety Program Plan is designed to improve the survivability of passengers and crew during an impact survivable postcrash transport aircraft cabin fire. Five major tasks are identified to accomplish the goal: (1) Postcrash Cabin Fire Hazard Characterization, (2) Laboratory Test Methodology Development, (3) Survival and Evacuation, (4) Fire Management and Suppression, and (5) Standards and Improvements. The program emphasizes the development of test methods and criteria for cabin interior materials that relate to flammability, smoke, and toxicity under postcrash fire conditions. Full-scale and model tests are performed initially to characterize the problem and identify governing parameters. A major activity is the correlation of small-scale and large-scale tests to determine what test or series of tests, test conditions, and data or scientific treatment of data best relate to postcrash cabin fire hazards. Quantification of the various hazards in terms of human survival will require studies to establish the escape impairment of irritant gases and develop a human survival model. Test method acceptability criteria will be derived based on a rational analysis incorporating computer models and cost/benefit computations. The program plan includes development or evaluation of cabin fire evacuation aids, including heat resistant evacuation slides, emergency lighting for a smoke-filled cabin environment and protective breathing devices, and fire management and suppression systems. Cooperative efforts with NASA are outlined which include the possible replacement of current urethane seat cushions and acrylic windows with advanced materials and the development of an interior materials data bank and cost/performance model.

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# METRIC CONVERSION FACTORS

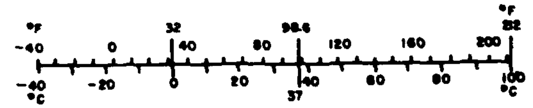
## Approximate Conversions to Metric Measures

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| in | inches | *2.5 | centimeters | cm |
| ft | feet | 30 | centimeters | cm |
| yd | yards | 0.9 | meters | m |
| mi | miles | 1.6 | kilometers | km |
| | | **AREA** | | |
| $in^2$ | square inches | 6.5 | square centimeters | $cm^2$ |
| $ft^2$ | square feet | 0.09 | square meters | $m^2$ |
| $yd^2$ | square yards | 0.8 | square meters | $m^2$ |
| $mi^2$ | square miles | 2.6 | square kilometers | $km^2$ |
| | acres | 0.4 | hectares | ha |
| | | **MASS (weight)** | | |
| oz | ounces | 28 | grams | g |
| lb | pounds | 0.45 | kilograms | kg |
| | short tons (2000 lb) | 0.9 | tonnes | t |
| | | **VOLUME** | | |
| tsp | teaspoons | 5 | milliliters | ml |
| Tbsp | tablespoons | 15 | milliliters | ml |
| fl oz | fluid ounces | 30 | milliliters | ml |
| c | cups | 0.24 | liters | l |
| pt | pints | 0.47 | liters | l |
| qt | quarts | 0.95 | liters | l |
| gal | gallons | 3.8 | liters | l |
| $ft^3$ | cubic feet | 0.03 | cubic meters | $m^3$ |
| $yd^3$ | cubic yards | 0.76 | cubic meters | $m^3$ |
| | | **TEMPERATURE (exact)** | | |
| °F | Fahrenheit temperature | 5/9 (after subtracting 32) | Celsius temperature | °C |

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.


## Approximate Conversions from Metric Measures

| Symbol | When You Know | Multiply by | To Find | Symbol |
|---|---|---|---|---|
| | | **LENGTH** | | |
| mm | millimeters | 0.04 | inches | in |
| cm | centimeters | 0.4 | inches | in |
| m | meters | 3.3 | feet | ft |
| m | meters | 1.1 | yards | yd |
| km | kilometers | 0.6 | miles | mi |
| | | **AREA** | | |
| $cm^2$ | square centimeters | 0.16 | square inches | $in^2$ |
| $m^2$ | square meters | 1.2 | square yards | $yd^2$ |
| $km^2$ | square kilometers | 0.4 | square miles | $mi^2$ |
| ha | hectares (10,000 $m^2$) | 2.5 | acres | |
| | | **MASS (weight)** | | |
| g | grams | 0.035 | ounces | oz |
| kg | kilograms | 2.2 | pounds | lb |
| t | tonnes (1000 kg) | 1.1 | short tons | |
| | | **VOLUME** | | |
| ml | milliliters | 0.03 | fluid ounces | fl oz |
| l | liters | 2.1 | pints | pt |
| l | liters | 1.06 | quarts | qt |
| l | liters | 0.26 | gallons | gal |
| $m^3$ | cubic meters | 35 | cubic feet | $ft^3$ |
| $m^3$ | cubic meters | 1.3 | cubic yards | $yd^3$ |
| | | **TEMPERATURE (exact)** | | |
| °C | Celsius temperature | 9/5 (then add 32) | Fahrenheit temperature | °F |



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### PROBLEM.

It is estimated that 39 percent of the fatalities in impact survivable transport aircraft accidents are a result of the effects of fire. Fire created by aircraft crashes invariably involves spilled fuel and, in many cases, cabin interior lining and furnishing materials. The role of interior materials in postcrash cabin fire survivability is controversial because of the apparent overwhelming dangers from the fuel fire itself. Federal Aviation Administration (FAA) flammability regulations (FAR 25.853, effective May 1972) specify that cabin materials cease burning on their own when subjected to a Bunsen burner test, which is believed to assure resistance in the material to ignition by a small flame. However, these materials will ignite and burn when exposed to the severe heating conditions of a fuel fire, and will produce heat, smoke, and numerous toxic gases that may prevent the safe evacuation of cabin occupants. Although the FAA has issued, in 1974 and 1975, regulatory proposals on smoke and toxicity, they were eventually withdrawn primarily because of the inability to relate results from existing test methods to the various cabin hazards confronting occupants by a real fire. The effect of many of these hazards, individually or even more so in combination, on the ability of a cabin occupant to successfully evacuate an airplane is unknown.

### PROGRAM OBJECTIVES.

The overall objective of the Aircraft Cabin Fire Safety Program is to characterize the transport aircraft cabin hazards created by an external fuel fire, especially the contribution of interior materials, and increase the survivability and safety of occupants in the event of a cabin fire by developing relevant fire test methods and criteria for interior materials, examining and fostering the use of improved materials, and examining and recommending effective fire management and suppression systems and evacuation aids.

### CRITICAL ISSUES.

As the Aircraft Cabin Fire Safety Program proceeds, certain critical issues must be considered. Three of these issues are as follows.

a. It is necessary to determine whether interior materials are a significant fire hazard relative to a postcrash fuel fire, or whether advanced materials provide a significant safety benefit in comparison to inservice materials. If either case is not true, resources should be redirected to support other measures for the improvement of cabin fire safety; e.g., fire management and suppression, evacuation aids, and antimisting fuel.

b. Heat, smoke, and toxic gases are measured during large- and full-scale tests; however, it is very difficult to predict with confidence the effect of these measured hazards on the ability of an occupant to survive and escape. Although this program plan provides for the development of a human survival model, such a model can obviously never be satisfactorily validated. Therefore, because of this difficulty in quantitating human hazard and survival, test data will usually be subject to some degree of interpretation.

c. Small-scale test methods for interior materials are extremely simplified compared to the complexities of the fire dynamics and hazards of a postcrash cabin fire. Therefore, it is uncertain if a determination can be made as to what test methods, test conditions, and data or scientific treatment of data best relate to the hazards created by interior materials during a cabin fire and, thus, could form the basis for materials selection. If this determination cannot be made with confidence, more emphasis will have to be placed on large-scale tests and, perhaps, modeling experiments to determine the safety benefit of alternate materials in order to encourage or require the usage of safer materials.

## PROGRAM TECHNICAL APPROACH.

Figure ES-1 outlines the five major program tasks, the various projects and activities within each task, and their functional relationships. The technical approach recognizes that safety improvements are possible once the characteristics of postcrash cabin fire hazards are measured (top block) and understood (left block, human survival limits). Once the nature of the problem is reasonably well understood, three approaches are available for improving fire safety: (1) management of materials, (2) management of fire, and (3) management of people. The emphasis of the present program is on management of materials through the development of laboratory test methods for usage in the selection of materials (center block). Projects and activities are planned to develop and study flammability, smoke, and toxicity test methods and problems, develop a method for combining various hazards into a single rating index and correlate small-scale and large-scale test results. Management of people is addressed under the survival and evacuation task (left block). Planned projects include examining emergency lighting systems in a smoke-filled cabin environment, developing means of improving the heat resistance of evacuation slides and reconsidering the use of protective breathing devices. Management of fire will consist essentially of a comprehensive three-phase study to determine the feasibility and cost/benefit of all available fire management and suppression concepts (right block). Ultimately, the described tasks will lead to standards and improvement (bottom block).

## ESTIMATED COMPLETION DATES.

Completion dates for those major projects and activities which can be estimated at this time are presented below:

a. Complete study of heat resistance of evacuation slides. 9/80

b. Establish cabin hazards (C-133) created by wide-body type of materials. 11/80

c. Complete evaluation of advanced emergency lighting concepts. 11/80

d. Complete Combined Hazard Index contract. 12/80

e. Recommend improved seat cushion replacements for urethane foams. 6/81

f. Characterize and define a design fire. 2/81

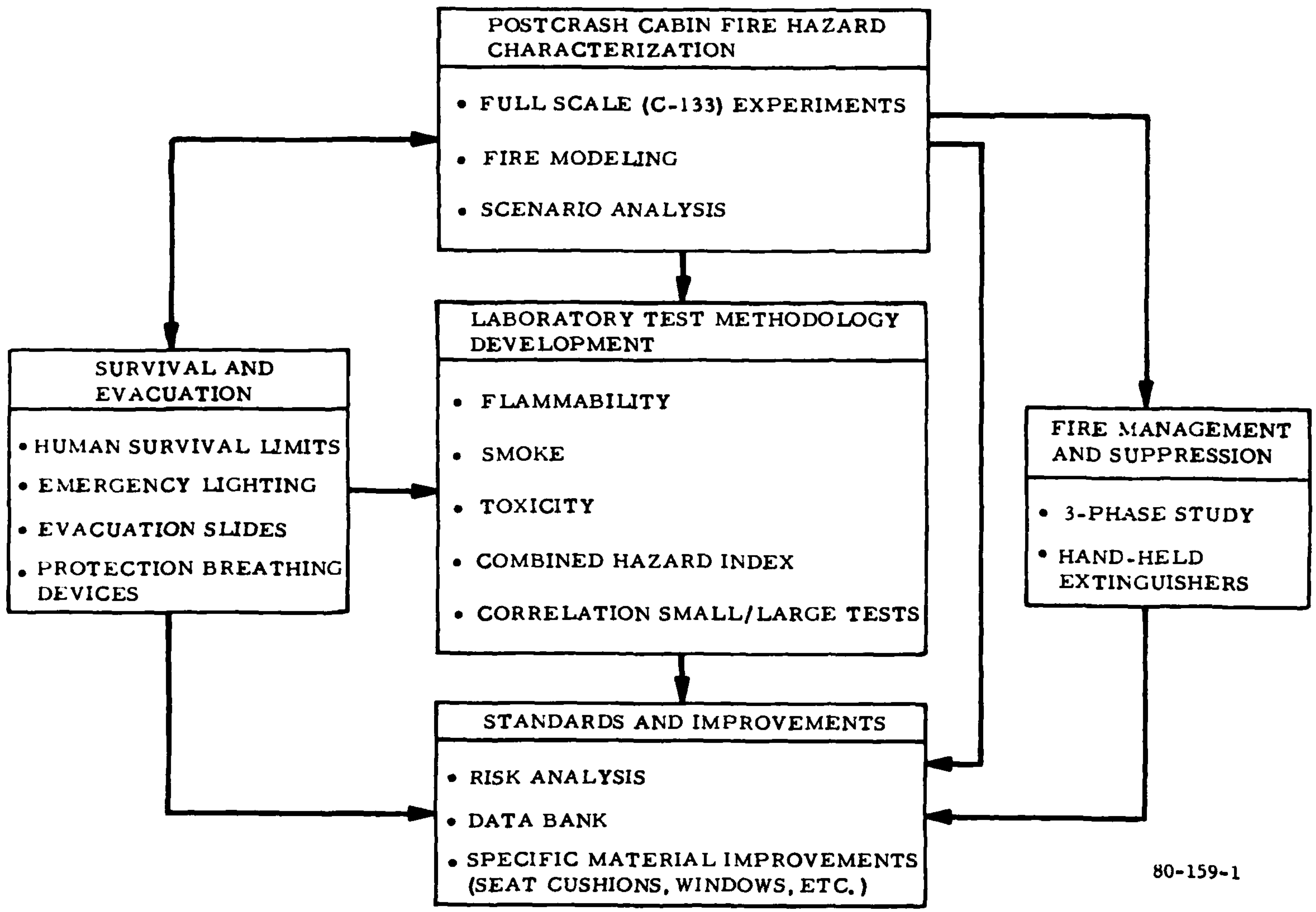


FIGURE ES-1. AIRCRAFT SYSTEMS FIRE SAFETY PROGRAM FUNCTIONAL RELATIONSHIPS AND WORKFLOW

| | |
|---|---|
| g. Establish reduction in cabin hazards (C-133) through usage of advanced materials. | 6/81 |
| h. Complete development of interior materials computer data bank with wide user availability. | 8/81 |
| i. Complete development of mathematical cabin fire model. | 8/81 |
| j. Upgrade/expand hand-held fire extinguishers advisory circular. | 12/81 |
| k. Develop FAA combustion toxicity test. | 12/81 |
| l. Develop risk analysis model. | 6/82 |
| m. Complete Technical Center pressure modeling studies. | 10/82 |
| n. Complete comprehensive study of feasibility and cost/benefit of fire management and suppression concepts. | 11/82 |
| o. Complete correlation study of small-scale and large-scale test results. | 12/82 |
| p. Derive small-scale test acceptability criteria for interior materials. | 1/83 |

PROGRAM MANAGEMENT AND INTERFACE.

The overall management of the Aircraft Cabin Fire Safety Program will be conducted by the Fire Safety Branch, ACT-350, Federal Aviation Administration Technical Center. Project work will be accomplished by functional groups at the Technical Center and Civil Aeromedical Institute (CAMI) and by contract, as required. Coordination with the National Aeronautics and Space Administration (NASA) FIREMEN Program is maintained primarily through interagency meetings and informal communications. The responsibilities of each agency are contained within a Memorandum of Understanding.

FUNDING REQUIREMENTS.

Total program contractural funding requirements are estimated below:

| FY-1980 | FY-1981 | FY-1982 | FY-1983 | FY-1984 |
|---|---|---|---|---|
| $1,900,000 | $2,600,000 | $1,800,000 | $1,000,000 | $1,000,000 |

## 1. INTRODUCTION.

### 1.1 CABIN FIRE PROBLEM.

A commercial aircraft is capable of transporting hundreds of passengers over long distances in a relatively short period of time. Thousands of gallons of flammable fuel are stored in the integral wind fuel tanks and consumed in flight while propelling the aircraft to its final destination. The passengers and crew are confined within a densely populated environment—the aircraft cabin—that is furnished and lined with a great variety and large quantity of complex synthetic (plastic) and natural polymeric materials. The potential dangers arising from an accidental fire seem evident from this brief description; however, the nature of these dangers and the means for their minimization have been and still are a subject of intense debate and controversy and, rightfully, are the central issues of this program plan.

An examination of transport aircraft accident statistics in the United States indicates that all fatalities which can be attributable to fire are the result of crash accidents during approach, takeoff, or landing (reference 1). The fire originates in most cases from the ignition of jet fuel released from fuel tanks damaged during the crash impact. It is estimated that about 15 percent of all fatalities in transport accidents are a result of the effects of fire; the remaining fatalities are, of course, due to impact. Normalizing the number of fire fatalities by the total number of fatalities in survivable accidents—those accidents in which one or more of the occupants survive the impact—produces a greater proportion of fire fatalities than exists in terms of all accidents. For example, an analysis of 29 impact survivable accidents for the period 1964 to 1977 indicated that 453 of 1162 fatalities (39 percent) were attributed to fire (reference 2). In summary, on the basis of accident analyses alone, it is evident that a very significant portion of the fatalities in survivable accidents is caused by fire, and that aircraft fire safety must be addressed in the context of the postcrash, external fuel fire because all fire fatalities occur in this type of accident.

Although all fire fatalities occur in crash accidents, some organizations have concentrated on the in-flight fire problem because of a fatal and dramatic in-flight cabin fire which occured in France in a Varig B-707 aircraft (reference 3). Fortunately, there is no documented incident over the continental United States of an uncontrollable in-flight fire originating within an accessible area of a transport aircraft cabin; and for this reason, the FAA has emphasized in its research, the postcrash cabin fire problem. Although fires do initiate occasionally in galley and lavatory areas, they have always been controlled by early detection and prompt extinguishment action by effectively trained crew members. In addition, the fire resistant nature of aircraft cabin materials probably has been another important factor in preventing uncontrollable in-flight fires.

FAA flammability regulations for interior materials were initially promulgated in 1947 and essentially required that materials experience slow burning in a horizontal orientation. These regulations have been upgraded periodically to assure that the "best" state-of-the-art materials are incorporated into the cabin design. The latest flammability regulations (FAR 25.853), adopted in May 1972, specify that all large usage materials be "self-extinguishing" in a

a vertical orientation when subjected to a small ignition flame (reference 4). The test method used to show compliance with the "self-extinguishing" requirement is often referred to as the vertical Bunsen burner test (reference 5). This test method reduces the probability of ignition by a small flame (thus, the in-flight fire safety benefit) and possibly the rate of flame-spread beyond the ignition source. However, under the intense conditions created by an external fuel fire, any organic material will pyrolyze, ignite, and propagate flame, and will emit heat, smoke, combustibles, and toxic gases, endangering the safe evacuation of occupants. The exact role of interior materials as a factor affecting survivability will depend on such governing factors as fuselage integrity and fuel fire size, evacuation rate, location of fires(s), ambient wind conditions, door opening locations and type of aircraft. Aside from these real world effects which cannot be accurately simulated in the laboratory, it is apparent that the major deficiencies of the Bunsen burner test are that it does not provide for (1) exposure to an intense ignition source or (2) the measurement and consideration of flame spread and production of heat, smoke, combustibles and toxic gases.

The FAA issued proposed regulatory notices in 1974 on toxicity (reference 6) and in 1975 on smoke (reference 7) for the purpose of including these factors, in addition to the then existent flammability requirements, during the certification testing of interior materials. Public responses to these notices were primarily negative. Opposition was based on such generally valid arguments as inadequate test methodology development, extreme expense of compliance for a questionable safety benefit, and the independent "piecemeal" nature of these regulatory endeavors in conjunction with a flammability retrofit proposal (reference 8). The latter argument was of concern because of the apparent interrelationship which exists between flammability and smoke and toxicity. These regulatory proposals on toxicity, smoke, and flammability (retrofit) were withdrawn by FAA and a Special Aviation Fire and Explosion Reduction (SAFER) Advisory Committee was created to advise FAA with regard to future aircraft fire safety research and regulation (reference 9).

This document is a long-term, comprehensive program plan to improve cabin fire safety, with greatest emphasis placed on the fire testing and evaluation of interior materials. All SAFER recommendations related to cabin fire safety have been incorporated into the program plan.

## 1.2 PROGRAM OBJECTIVES.

The overall objective of the Aircraft Cabin Fire Safety Program is to characterize the transport cabin hazards created by a postcrash external fuel fire, especially the contribution of interior materials, and increase the survivability and safety of occupants in the event of a cabin fire by developing relevant fire test methods and criteria for interior materials, examining and fostering the use of improved materials, and examining and recommending effective fire management and suppression systems and evacuation aids.

Specific objectives of the program are to:

a. Determine, by conducting full-scale tests for specific scenarios, the cabin hazards created by an external fuel fire and the contribution of interior materials to the overall cabin hazard.

b. Develop and determine the validity and utility of physical and mathematical fire modeling as an alternate or supplement to full-scale tests for the purpose of predicting or measuring cabin fire spread and hazard development.

c. Develop small-scale tests that measure the flammability, smoke, and toxic gas emission characteristics of cabin materials and correlate with full-scale or mockup cabin hazard data obtained for a postcrash scenario consisting of a large external fuel fire adjacent to a fuselage opening.

d. Develop and validate a methodology for combining small-scale test measurements of flammability, smoke, and toxicity into a unified hazard index (Combined Hazard Index or CHI).

e. Determine escape impairment limits for major irritant gaseous combustion products and develop a "state-of-the-art" human survival model for predicting the "theoretical escape time" of humans exposed to cabin fire hazards.

f. Examine and recommend cabin fire management and suppression systems and evacuation aids, including emergency lighting and protective breathing devices, that improve the survivability of cabin occupants.

g. Develop a computer fire test data bank with broad user availability for inservice and candidate cabin interior materials.

h. Identify those inservice cabin materials wherein economic and practical alternate materials are currently available or under development, and foster the replacement of these materials by demonstrating safety benefit during realistic fire tests.

i. Related to item h above, recommend a near-term replacement for polyurethane seat cushions.

j. Update and expand FAA requirements for hand-held fire extinguishers.

k. Develop methods of risk analysis related to cabin fire safety.

l. Recommend test methods and criteria, and reflective coatings, to improve the radiative heat resistance of emergency evacuation slides.

## 1.3 CRITICAL ISSUES.

As the Aircraft Cabin Fire Safety Program proceeds, related critical issues must be identified and addressed. Several of these issues are discussed in the below:

a. Although unlikely, it is possible that planned full-scale cabin fire tests will indicate that, compared to the fuel fire, interior materials do not contribute to postcrash survivability. If this is clearly the indication then the resources now devoted toward testing and evaluating cabin materials should be redirected toward fire management and suppression, evacuation aids, and antimisting fuel.

b. If currently used interior materials have an effect on postcrash fire survivability, it remains to be seen if advanced organic material systems can provide a significant incremental safety benefit. If a safety benefit can clearly

be derived, the program should proceed as planned in this document. However, if an exhaustive evaluation of alternate organic material systems does not reveal a significant safety benefit, then the program should be redirected as described in the above paragraph.

c. A major problem exists with regard to the interpretation of the effect of heat, smoke, and toxic gases measured during large and full-scale tests on human survival and escape potential. Reliable information on human tolerance and survival limits for irritant gases are nonexistent; although research is planned in this program plan to begin to gather this information, it will probably not become available for at least several years. The combined effect of various hazards on human survival and escape has received very little attention by researchers. At this time it is even uncertain as to what major hazards are present during a postcrash cabin fire. The quantitative effect of smoke obscuration on survival needs to be determined. Because of these technical deficiencies, within the next several years it will be necessary to interpret large and full-scale fire test data in terms of relative measurements or on the basis of crude survival models. This will result in test data that is interpretative, and may make the decisions described in the preceding paragraphs somewhat subjective.

d. Small-scale fire test data, whether for flammability, smoke, or toxicity, are usually obtained for single, small test specimens under steady-state test conditions, and the test results are strongly dependent on the actual test conditions used. Real fires are dynamic in nature and involve a complex system of materials. It is generally accepted that standardized small-scale fire tests do not directly relate with full-scale tests or real fires. Fundamental questions about combustion processes and fire dynamics must be answered before relevant small-scale test methodologies can be developed. Although numerous standardized flammability tests are available, as well as at least one standardized smoke test (reference 10),—all with disclaimer statements pertaining to real fire relevancy—no standardized toxicity tests are in existence. Also, although FAA has under development a CHI test methodology, its great dependency on mathematical fire modeling and the transformation of numerous hazard measurements to human escape time make its near term application very unlikely. There is a recognized and generally accepted credibility gap in small-scale fire tests for interior materials. It should be recognized that cabin interior material selection by industry is based on many aspects besides these small-scale fire tests. Some other considerations are demonstrated safety benefit, cost/benefit analysis, compatability of new materials with existing processing equipment, durability, strength, asthetics, and servicing requirements.

e. The mathematical modeling of enclosure fires, such as within a furnished aircraft cabin, is in an infant state of development. Before cabin fire models can be applied to CHI methodologies currently under development and cost/benefit analyses, considerable research and development (R&D) must be performed. Overall program planning will proceed on the assumption that very limited cabin fire computer models will be available in the near future. Although physical fire modeling has a sound technical basis in the areas of home fires and corridor fires, this technology requires considerable effort in development and validation for the aircraft fire problem.

f. Technological breakthroughs may be required to make substantive improvements in aircraft cabin fire safety solely by changing the nature of interior materials. Other safety concepts must be periodically reexamined in light of

current advances in materials testing and evaluation R&D; namely concepts of fire management and people management (crew training, passenger education and personal protection devices).

g. It is difficult to predict consistent evacuation responses of passengers in crashes which create external/internal fire, dense smoke, and toxic combustion products. Variables such as passenger group panic and impairment of judgment during evacuation from toxic products cannot be effectively and safely incorporated into a research protocol. The effects of visibility and emergency lighting improvement will be evaluated through comparative testing under conditions not hazardous to human subjects.

## 1.4 GENERAL TECHNICAL APPROACH.

The general technical approach is illustrated in figure 1 and recognizes that the ultimate goal of the program is to improve postcrash cabin fire safety. Safety improvements are possible once the characteristics of postcrash cabin fire hazards are measured and understood. This information is obtained by performing well-instrumented and controllable series of full-scale and physical modeling tests. The present emphasis at the Technical Center is to conduct this type of testing. Once the nature of the problem is reasonably well understood, three approaches are available for improving fire safety: (1) management of interior materials, (2) management of fire, and (3) management of people. The present program is mainly concerned with developing test methods and criteria for managing the selection of interior materials; however, lower level efforts to seek or examine fire and people management solutions are either underway or will be undertaken this fiscal year to assure a comprehensive systems approach.

## 1.5 PROGRAM STRUCTURE.

The aircraft systems fire safety program plan is structured to provide concurrent development in four areas:

a. Characterization of Postcrash Cabin Fire Hazards
b. Management of Materials
. Management of Fire
d. Management of People

Currently the greatest emphasis is being placed in the first two areas. Figure 2 outlines the Aircraft Cabin Fire Safety Program tasks and projects, its functional relationships, and work flow. The plan is based on five essential tasks:

1. Postcrash Cabin Fire Hazards Characterization.
2. Laboratory Test Methodology Development.
3. Survival and Evacuation.
4. Fire Management and Suppression.
5. Standards and Improvements.

Each task is composed of individual projects as described in sections 2.1 to 2.5.

# 2. AIRCRAFT CABIN FIRE SAFETY PROGRAM DESCRIPTION.

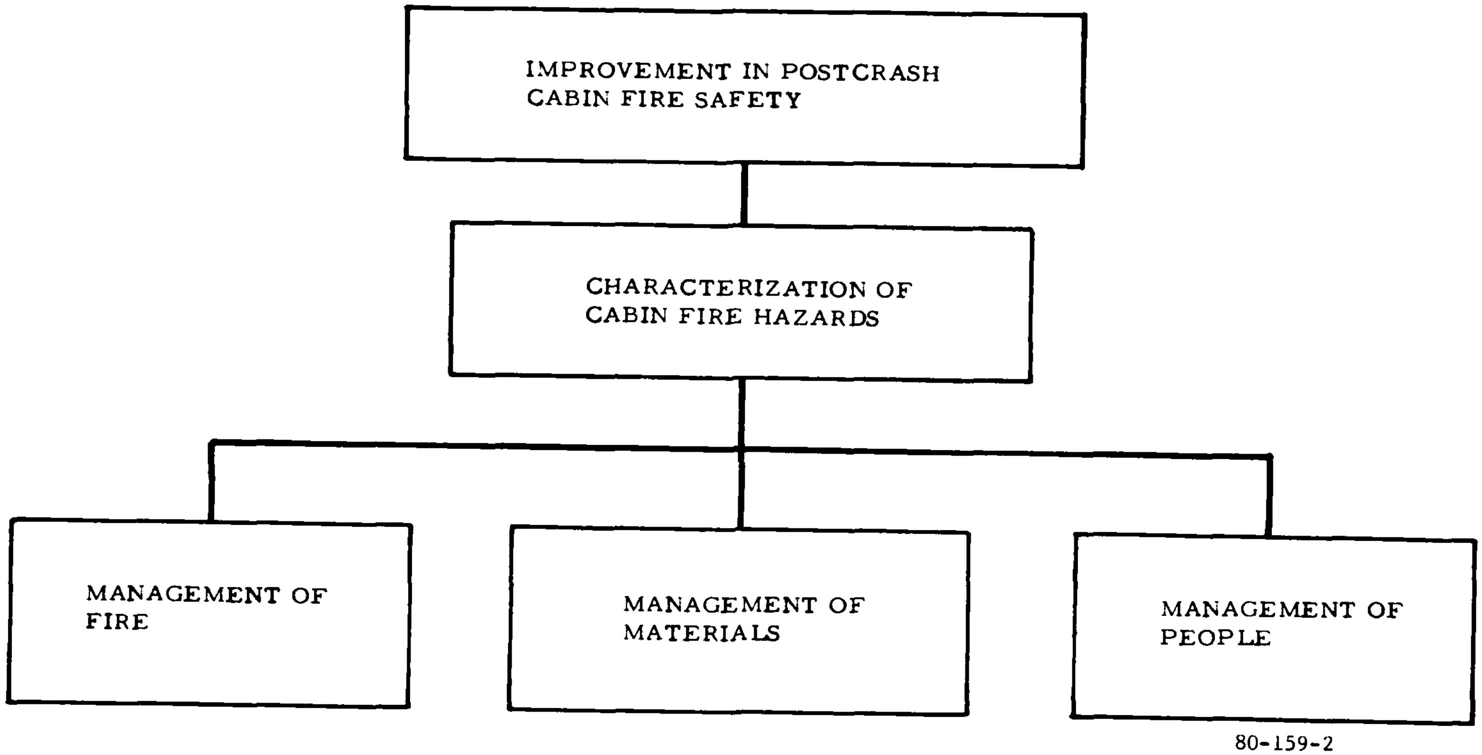


FIGURE 1. AIRCRAFT SYSTEMS FIRE SAFETY PROGRAM GENERAL TECHNICAL APPROACH

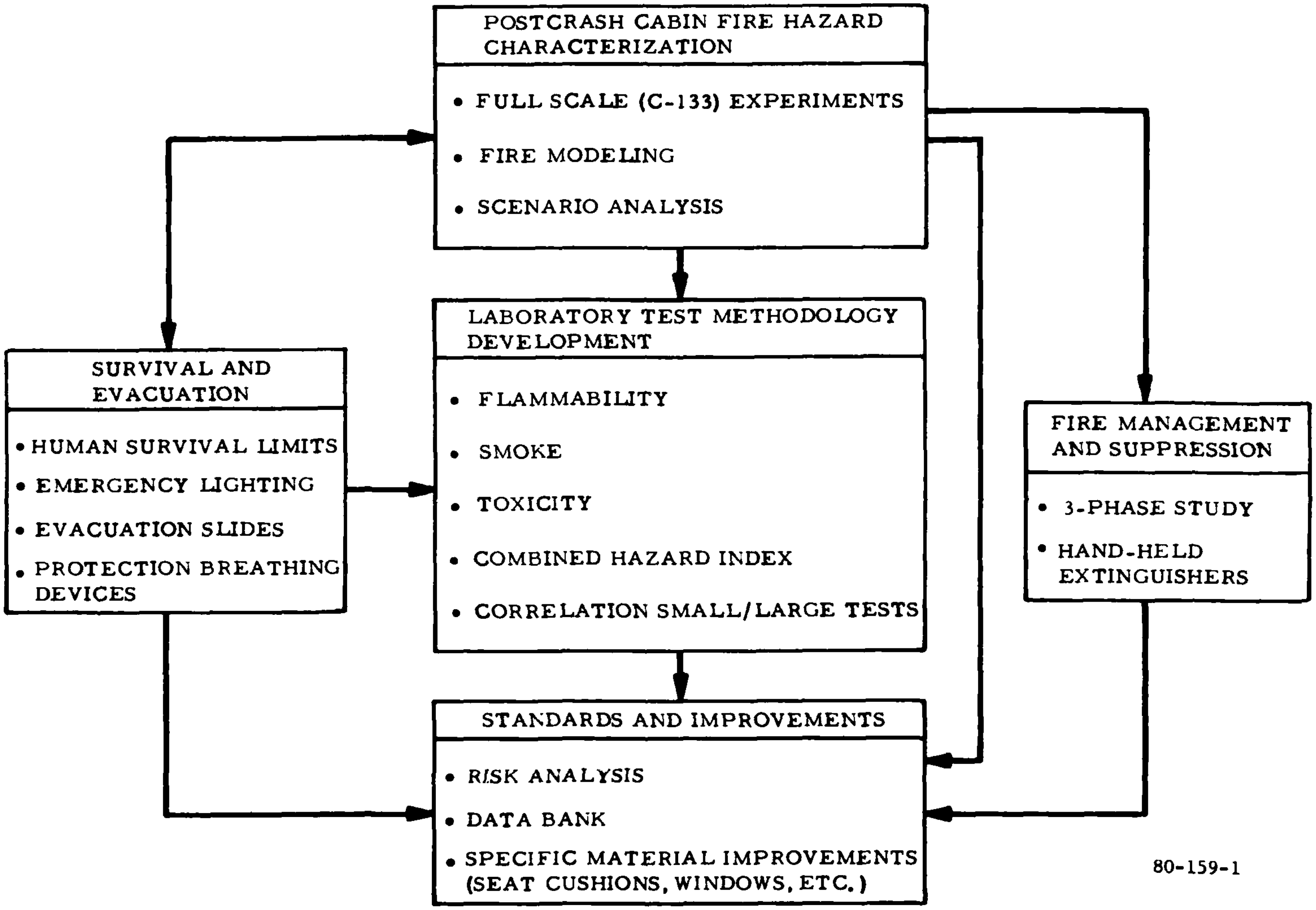


FIGURE 2. AIRCRAFT SYSTEMS FIRE SAFETY PROGRAM FUNCTIONAL RELATIONSHIPS AND WORKFLOW

## 2.1 POSTCRASH CABIN FIRE HAZARDS CHARACTERIZATION.

Before major progress can be made in improving cabin fire safety, it is essential that the cabin hazards created by an external fuel fire be reasonably well understood. Detailed information on fire spread and rate of hazard buildup cannot be derived from examining a burned-out aircraft cabin at the site of an accident. The most appropriate means available for gathering this information is by conducting a series of controllable and well instrumented experiments in a full-scale cabin simulator or cabin model. The broad purpose of these experiments is to measure the temporal and spatial distribution of various cabin fire hazards and determine the influence of various configurational and environmental factors.

### 2.1.1 Full-scale (C-133) Experiments.

A full-scale, wide-body cabin type of test article has been constructed at the Technical Center from a surplus C-133 aircraft and a large number of external fuel fire experiments have been performed over the past several years. A detailed description of the test article is contained in references 11 or 12, and a drawing of the C-133 test article is shown in figure 3. The postcrash fire scenario that is used in the C-133 was selected to assure the greatest probability of the maximum contribution of interior materials, relative to the external fuel fire, to the overall cabin hazard. An 8- by 10-foot external fuel fire is positioned adjacent to a fuselage opening the size of a type A door near the front of the airplane. A similar opening on the same side of the fuselage exists in the back. Measurement and sampling probes are located throughout the cabin to determine the spatial and temporal distribution of hazards. Instrumentation is currently used for measurement of temperature, heat flux, smoke density, and various gases either continuously or from periodic batch samples. The gases which are analyzed presently include CO, $CO_2$, $O_2$, HCN, HF, HCl, and total yields of other selected species. White rats are used to determine the incapacitating and lethal nature of the C-133 environment.

#### 2.1.1.1 Major Projects.

The C-133 test article could be properly utilized for any of a variety of studies described under subsequent tasks in sections 2.2 to 2.5. Several such examples include the evaluation of advanced fire management and suppression systems/concepts (section 2.4) and advanced material systems which are candidate cost/effective replacements for current materials (e.g., seat foams and windows, section 2.5). The degree of success and progress during planned studies and developments by various organizations (FAA, NASA, SAFER, and industry) will determine the exact areas of C-133 utilization beyond the following firm plans of:

a. Defining cabin hazards within a bare interior.

b. Defining cabin hazards within an interior furnished with "typical" wide-body materials.

c. Characterizing a design fire.

d. Defining cabin hazards within an interior furnished with advanced NASA materials.

e. Studying the correlation between small-scale and large-scale test results.

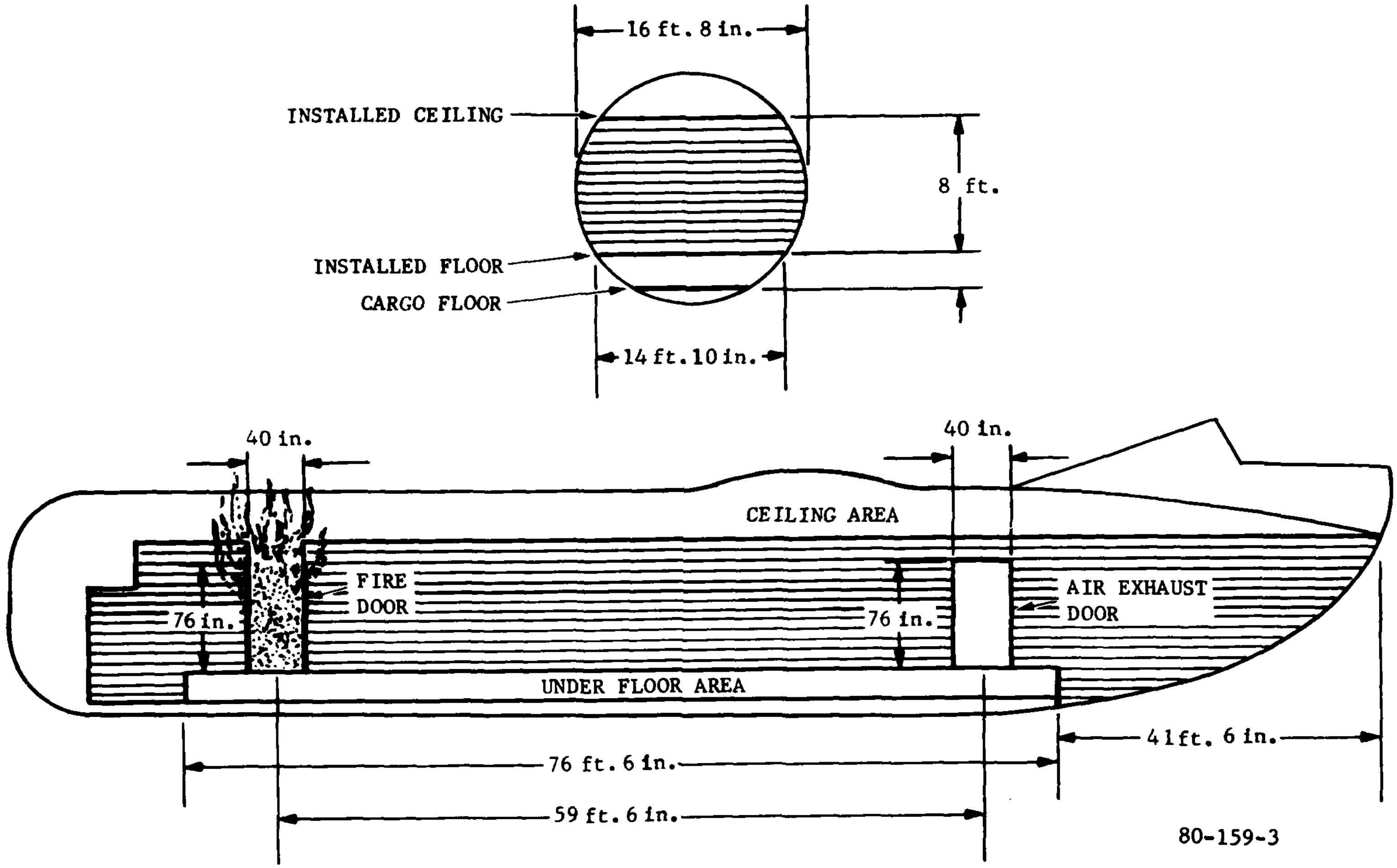


FIGURE 3. WIDE-BODY CABIN FIRE TEST ARTICLE

#### 2.1.1.2 Cabin Hazards Within a Bare Interior.

This completed project consisted of conducting a large series of tests with the test article devoid of interior materials. The purpose was to develop a realistic and repeatable external fuel fire source, determine the cabin hazards exclusively resulting from the fuel fire, and determine the fire conditions that interior materials would be exposed to. A final FAA report was published in December 1979 (reference 12). The following summarizes the most important findings:

a. Ambient wind is the most important factor influencing the cabin hazards.

b. Significant vertical profiles (stratification) of heat, smoke, and toxic gases occur inside the cabin.

c. Heat and smoke individually are more hazardous than carbon monoxide in a cabin environment dominated by burning fuel.

d. Oxygen depletion without interior materials is insignificant when the cabin is ventilated.

#### 2.1.1.3 Cabin Hazards Within an Interior Furnished with "Typical" Wide-Body Materials.

##### 2.1.1.3.1 Objective.

The objective of this project is to determine the contribution of burning interior materials, relative to a postcrash external fuel fire, to the overall cabin fire hazard. A secondary objective is to study the relative importance of various fire hazards, including heat, smoke and toxic gases, on occupant survivability.

##### 2.1.1.3.2 Background.

Significant controversy exists over the importance and role of cabin materials in effecting occupant survivability during a postcrash cabin fire originating from an external fuel fire. An unpublished cursory in-house study indicated that approximately 1/3 of commercial aircraft fire fatalities are attributable to interior materials. Conversely, it has been argued that there is no evidence of fire fatalities ever having resulted from burning wide-body type of interior materials. The SAFER Technical Group on Compartment Interior Materials recommended that top priority be given to this project in order to "determine whether a problem exists with interior materials."

##### 2.1.1.3.3 Technical Approach.

A 20-foot length of the C-133 test article will be completely furnished and lined with "typical" wide body materials; e.g., seats, carpeting, ceiling and sidewall panels, and overhead stowage bins. Duplicate external fuel fire tests are planned for each of three wind conditions: (1) quiescent wind, (2) quiescent wind with a momentary gust, and (3) steady wind. Recent C-133 experiments without interior materials indicate that the cabin hazards resulting from the fuel fire are survivable at an aft fuselage station for at least 5 minutes, for all three conditions. Also, the magnitude of thermal radiation and flame penetration at the fuselage opening adjacent to the fire increases in the order of the conditions

enumerated above; consequently, the burning of the interior will vary accordingly. By simply comparing the cabin hazards at the same aft station with and without interior materials, the importance of interior materials can be determined for the test conditions studied.

2.1.1.4 Characterization of a Design Fire.

2.1.1.4.1 Objective.

The objective of this project is to define a design fire(s) to be used as a standard for large-scale cabin material fire tests.

2.1.1.4.2 Background.

There have only been a surprisingly small number of realistic, full-scale fire tests conducted in the past, and these tests have differed from one another in terms of the fire threat studied. Examples of fire sources used include large external fuel fires, small external fuel fires, small jet fuel or alcohol internal fuel fires, large radiant heaters with piloted ignition sources, etc. The SAFER Compartment Interior Materials Technical Group recognized this divergence in full-scale test methodology and recommended that a design fire be defined. A design fire would furnish the following benefits: provide a solid baseline against which to gauge improvements in interior materials, focus the efforts of various test organizations into working the same problem, and provide a well-defined fire threat. The materials technical group felt a design fire should be defined for a scenario consisting of a postcrash external fuel fire adjacent to an intact fuselage with door openings. At this time the C-133 test article best meets these requirements.

2.1.1.4.3 Technical Approach.

Basically, the characteristics of the design fire will be established to provide a desired survivability time. As described in paragraph 2.1.1.3, C-133 tests with the interior furnished with "typical" wide-body materials will help establish the design fire. Once the test conditions are established, the fire will be standardized in terms of fuel type and quantity, size of fire, and wind velocity. The design fire will also be characterized in terms of flame penetration and coverage of interior materials, radiative heat flux and temperatures at various typical material locations, and oxygen depletion near the ceiling. The design fire will be described in sufficient detail to allow for its duplication or simulation by other test organizations.

2.1.1.5 Cabin Hazards Within an Interior Furnished with Advanced NASA Materials.

2.1.1.5.1 Objective.

The primary objective of this project is to determine the incremental increase in postcrash cabin fire safety that can be provided by the "best" advanced interior materials in comparison to typical inservice wide-body materials.

2.1.1.5.2 Background.

Are currently used cabin interior materials the safest available in the context of a survivable postcrash fire environment? What incremental safety benefit

is attainable by replacing current materials with the "best" advanced materials under development by NASA and industry? These questions must be answered in order to rationally evaluate regulatory strategies and help guide the direction of future research relevant to cabin fire safety. The SAFER R&D Review Subgroup of the Compartment Interior Materials Technical Group recommended that tests be conducted in the C-133 with the interior lined and furnished with advanced materials in order to determine the incremental safety benefit afforded by these "best" materials.

#### 2.1.1.5.3 Technical Approach.

The technical approach will be identical to that planned for the evaluation of "typical" wide-body materials, as described in section 2.1.1.3, except that the "best" advanced materials will be tested. This project will rely heavily on expertise provided by the NASA Ames Research Center to select and fabricate materials. A close cooperative FAA/NASA project is envisioned. Emphasis as now viewed will be placed on advance panels and seat systems; these appear to be the most important usage categories from a fire safety standpoint. Because of the inability to predict full-scale fire behavior of materials based on small-scale tests and the possible importance of individual material interactions in a real system of materials, it will be necessary to examine at least several material combinations or systems under the design fire conditions derived in section 2.1.1.4.

### 2.1.1.6 Studies to Correlate Small-Scale and Large-Scale Test Results.

It is now visualized that the C-133 test article will be utilized for the extremely important studies to correlate small-scale laboratory tests for cabin material with large-scale fire test results. The C-133 is the most extensively instrumented test article now existent at the Techical Center for fire studies and is thus a logical first choice for the correlation study. However, future developments and recommendations which cannot be predicted beforehand may determine whether the C-133 is actually used for the correlation study (see section 2.2.2).

### 2.1.1.7 Full-Scale Fire Test Facility.

A full-scale fire test facility capable of housing the C-133 test article is now under construction at the Technical Center. The projected completion date for the facility is July 1980. The facility is composed of a test bay and an operations wing. The test bay is 180-feet long, 75-feet wide, and 45-feet high, and is designed to withstand the environment produced by a 20-foot square fuel fire at its center. The operations wing will contain a test control and computer area, offices, a mechanical room, and shop/storage area. The new facility will significantly accelerate the C-133 test program for the following reasons:

a. By providing an environment isolated from random ambient wind fluctuations which destroy test repeatability (tests are now conducted at approximately 0600 on those days when meteorological predictions indicate zero ambient wind).

b. By allowing for the conduct of tests on a regularly scheduled basis independent of the weather, particularly the cancellation effects of wind and rain.

c. By permitting testing during the cold winter months (C-133 outdoor tests are now terminated for 3 months during the winter).

2.1.1.8 Major Project Milestones.

Major project milestones are graphed in figure 4. The shorter project schedules, after the move into the new facility, reflect the accelerated nature of the testing made possible by an all weather/all season test environment. By far the longest test schedule is estimated for the correlation studies because of the complexity of and lack of precedent for this type of undertaking.

2.1.2 Fire Modeling.

Although full-scale tests are the most definitive sources of data for specific fire scenarios, full-scale test work is costly and time consuming. In addition, a specific full-scale test bed, such as the C-133, generally lacks the flexibility to allow for an easy change of the scenario and thereby is not capable of generating a broad enough data bank to represent the range of postcrash fire possibilities.

To circumvent these shortcomings, the FAA is sponsoring the development and application of two complementary approaches to fire modeling. The first, physical modeling of fire, involves development of reliable techniques for conducting aircraft fire tests on a small scale through the use of scaled fuselage models. Two physical modeling methods are available: Froude modeling at atmospheric pressure and pressure modeling at elevated pressures (reference 13). The second modeling technique, mathematical modeling of fire, involves the development of a semi-empirical computer program for predicting the spread of fire and its hazardous products within an aircraft cabin.

2.1.2.1 Objectives.

The general objectives of the fire modeling effort are as follows:

a. Develop reliable physical fire modeling techniques that allow rapid and wide-ranging postcrash cabin fire tests to (1) broadly evaluate the effects of different interior materials and material systems, (2) examine the effects of different fire scenarios, ambient environmental conditions (e.g., winds), and configurational factors (e.g., number and location of door openings), and (3) assist in the determination of full-scale test conditions most likely to provide useful data.

b. Develop a reliable mathematical postcrash cabin fire model and computer program to predict the effects of changing cabin design and interior materials on fire spread and hazard development.

2.1.2.2 Background.

Both physical and mathematical modeling of fire have been active areas of research in nonaviation fields for over a decade. The FAA has supported the application of physical and mathematical modeling to cabin fire safety problems over the last 3 and 5 years, respectively. The major efforts have been the development of physical modeling approaches at the Technical Center and the development of a comprehensive engineering mathematical model, Dayton Aircraft Cabin Fire (DACFIR), at the University of Dayton Research Institute (UDRI). The modeling efforts in the future will represent the most economical means of evaluating the efficacy of cabin

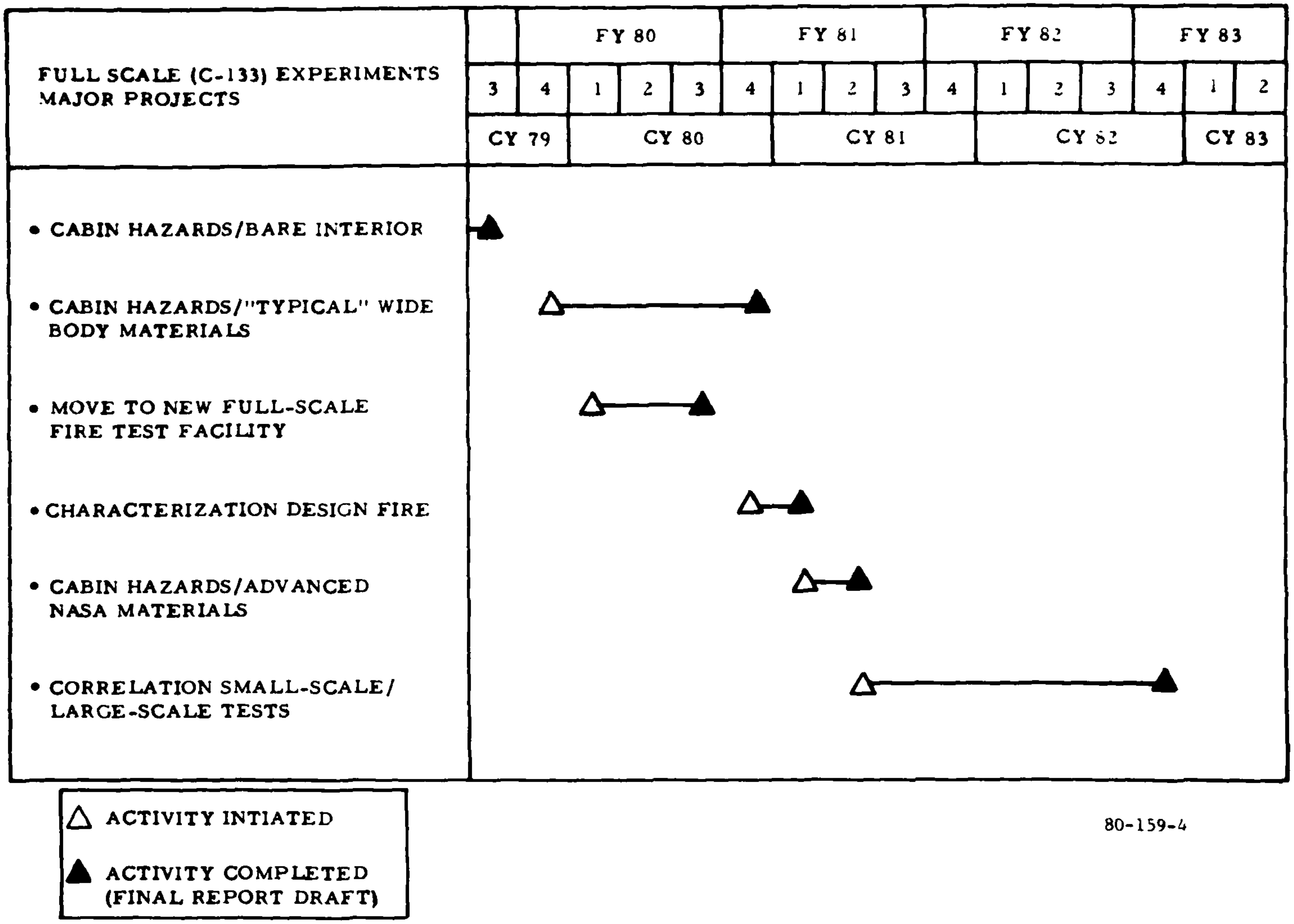


FIGURE 4. FULL-SCALE (C-133) PROJECTS MILESTONES

design change proposals for the purpose of enhancing the survivability from fire related hazards after an aircraft crash. Both physical and mathematical modeling will provide tools to develop a wide enough data base to ensure that regulations relating to materials, design, and evacuation procudures will indeed provide for improved survivability under a broad range of crash scenarios.

#### 2.1.2.3 Work-To-Date.

The physical modeling work at the Technical Center to date has yielded the following major accomplishments:

a. Definition of radiative flux through a fuselage doorway from a large external pool fire, and development of theoretical relationships for prediction thereof (reference 14).

b. Development of sizing criteria for fires used in the C-133 wide-body tests.

c. Characterization of the effects of wind and door openings on hazard development in a fuselage from an external fuel fire (references 15 and 16).

d. Characterization of temperature stratification in a fuselage caused by the fire involvement of cabin materials exposed to the intense heat flux from an external pool fire.

In addition, a contractual pressure modeling study at the Factory Mutual Research Corporation (FMRC) has demonstrated that nominally "self-extinguishing" in-use materials in a vertical orientation will, in fact, burn when involved in a major postcrash fire (reference 17). A byproduct of this work is a new technique for ranking the relative flammability characteristics of cabin materials. However, this technique is not readily available for utilization by other organizations because it involves testing at elevated pressures of up to 30 atmospheres.

The DACFIR mathematical model developed at UDRI has most recently been validated against fire experiments in the NASA Boeing 737 test bed at Johnson Space Center. To date, the model has been developed to predict flamespread between seats for an in-flight type of fire scenario (fire ignition source wholly contained within cabin). The model relies on input data obtained from the Ohio State University (OSU) fire test chamber, which is a small-scale fire test, to predict material performance.

#### 2.1.2.4 State-of-the-Art.

In the physical modeling area, the work is currently divided in two areas. The first is Froude modeling wherein a fuselage is judiciously scaled down in size to provide a test article to investigate a specific aspect of postcrash cabin fire. For instance, the bulk of work to date has been done with a mild steel duct built to 1/4-scale of the C-133. However, smaller articles were adequate for studies of radiation from pool fires. The major scientific findings have been development of the techniques to scale down pool fires and the demonstration that external pool fires can probably be treated within the Froude modeling conceptual framework (reference 16). Prior to this work at the Technical Center, Froude modeling had been applied exclusively to fires within enclosures.

The other physical modeling approach, pressure modeling, involves conducting scaled down tests at high pressures (up to 500 pounds per square inch). This technique, although more costly and complex than Froude modeling, is useful for its ability to accurately simulate flame spreading and other transient processes.

It should be noted that physical modeling techniques really involve a transfer of technology from other areas, such as, room fires and corridor fires rather than establishment of untried technology. The developmental efforts primarily involve practical problems of adapting the technology to aircraft for the first time.

The mathematical modeling on the other hand involves the development of a new technology and as such must be expected to show unforeseen needs and complications. The existing DACFIR model attempts to predict flame spread from an ignition fire wholly contained within the cabin, and the evolution of heat, smoke, and toxic gases based on inputs from a small-scale fire test. However, the relevancy of the small-scale tests to the full-scale fire event is controversial, and some of the small-scale data, in particular, that of flame spread rate, is very inaccurate. In addition, the currently formulated model cannot predict with good accuracy the behavior of the fire plume as it spreads across the ceiling, or the fire development across various furnishings and paneling, nor the details of various gas dynamic phenomena such as stratification and air entrainment. Because the objective of the mathematical modeling is the development of a predictive tool, the dependence on small-scale tests and problems of fire development and gas dynamics must be addressed in the near future. In addition, the DACFIR program will be redirected to address the type of scenario under study in the C-133 test article.

2.1.2.5 Technical Approach.

In the physical modeling area, the in-house work at the Technical Center will include 1/4-scale model testing, Froude modeling, and pressure modeling.

2.1.2.5.1 1/4-Scale Model Testing.

The 1/4-scale model will continue to be used as a quick-reaction tool for evaluating material systems flammability, fuselage burnthrough, and new materials, such as, advanced epoxy windows under development at NASA Ames Research Center. It will also possibly be used to study broad effects on cabin hazards that result from different fire scenarios. The latter is necessary to provide some assurances that new materials developed against a design fire threat (section 2.1.1.4) are also beneficial under other postcrash fire scenarios.

2.1.2.5.2 Froude Modeling.

An already completed 56-foot model will be used to evaluate heat, smoke, and gas movement from burning materials and compartmentation concepts. Instrumentation for continuously recording the primary gases CO, $CO_2$, and $O_2$ will be implemented into the test program. A model of the full-scale fire test facility will be constructed and used to evaluate large fire test conditions before they are attempted in the actual facility.

### 2.1.2.5.3 Pressure Modeling.

A pressure modeling facility will be established at the Technical Center that will be unique in the world because of its length to diameter ratio. Only with a cylindrical vessel can an aircraft fuselage be pressure modeled accurately. The pressure modeling facility will be primarily used to study transient flame spread and hazard development processes in a small cabin model and to develop a simplified small-scale test for measuring the rate of flame spread across the surface of a material.

In the mathematical modeling area, the DACFIR program will be developed further to include an external fuel fire as an ignition source, to include compartmentation effects, and to develop a graphic display system to show fire progression. The validation work with the NASA data will be thoroughly analyzed to identify both strengths and weaknesses of the computer program. In addition, a workshop will be used as the vehicle to transfer this technology to the aircraft industry.

In a supportive role to the DACFIR model there will be several other projects. Contracts will be let in the following areas with potential application for improving the DACFIR model:

a. A theoretical model to predict the thermal degradation of seat and carpet materials based on physical and chemical properties. This effort would provide an alternate to the present approach used in the DACFIR model of taking material emission rate input data from small-scale tests. Another potential application of a successful thermal degradation model (thermochemical analysis) would be the development of design criteria for materials based on simple physical properties.

b. Two-dimensional field model solution of longitudinal spread of products of combustion in a fuselage.

c. Analysis of radiation impact on the lower part of the cabin from the ceiling smoke layer with inclusion of ceiling radiation and smoke blocking. This study will provide some insight into the validity of a two-zone pyrolysis model for approximating a cabin fire.

d. Theoretical treatment of ambient wind and fuselage door opening on external fuel fire penetration through a fuselage opening.

The latter effort will help tie the mathematical and physical modeling work together and will be part of a larger effort including:

1. A rigorous development of the appropriate equations and nondimensional terms for Froude modeling the postcrash cabin fire.

2. A comprehensive study of Froude modeling the external pool fire at several different scales, including interior materials as a fire source.

### 2.1.2.6 Major Milestones.

Major milestone estimates are graphed in figure 5. Current efforts include: development/validation of the DACFIR mathematical model at UDRI, ceiling materials pressure modeling at FMRC, and studies related to Froude modeling at the Technical

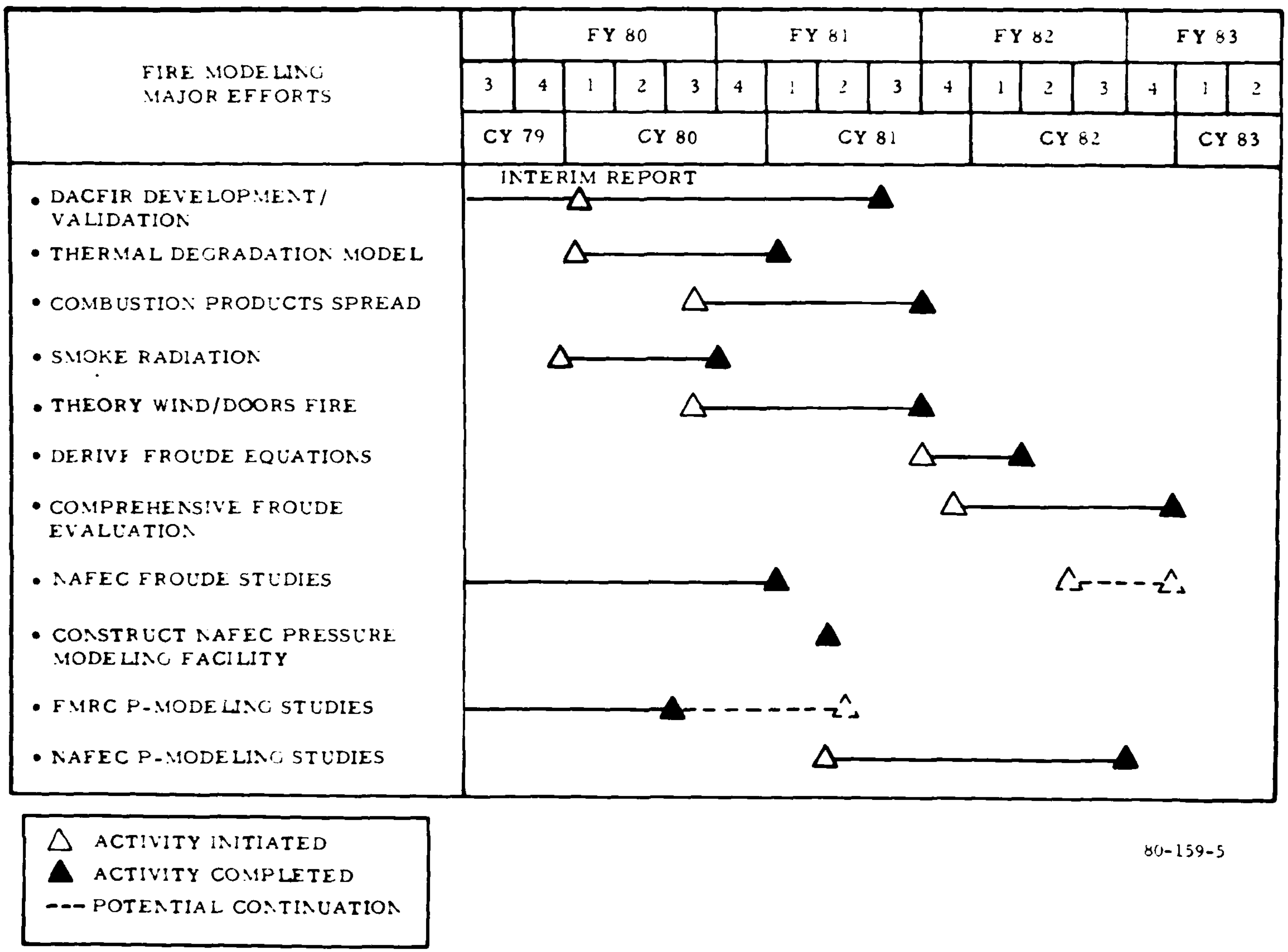


FIGURE 5. FIRE MODELING MILESTONES

Center. A number of contracts will be awarded in FY-80 to aid in the development of the DACFIR program and the fluid dynamics of the interaction of an external fuel fire with the aircraft fuselage. Specific areas of application of these modeling techniques were intentionally omitted because this will depend on the degree of success of the developments.

2.1.3 Postcrash Fire Scenario Analysis.

A contractual study will be awarded to analyze postcrash cabin fire accident scenarios. A spectrum of crash fires will be described in terms of a specific list of items of interest; e.g., fire size, evacuation time, wind conditions, integrity of fuselage, etc. This information will be retrieved from National Transportation Safety Board (NTSB) accident files. The contractor will develop criteria to be used for the selection of a scenario in which interior materials would be a significant contributory factor to survival. The selection of the scenario and the criteria applied will be of value in the development of a design fire under section 2.1.1.4. The contractor will attempt to estimate the probability of occurrence of the various crash fire scenarios contained in the spectrum of crash fires. This probability distribution function will be needed in a risk analysis computer program (section 2.5.1).

## 2.2 LABORATORY TEST METHODOLOGY DEVELOPMENT.

In order to impart some degree of fire safety to an aircraft cabin interior, materials are screened using small-scale fire tests. These tests fall into three categories: flammability, smoke, and toxicity.

FAA restrictions on cabin materials are limited to a flammability requirement contained in FAR 25.853 (reference 4). Fire researchers usually discuss the flammability of a material in terms of its tendency to resist ignition, propagate flame, generate heat, produce a combustible product or flashover. Flammability measurements in most test methods simply involve operator determination of ignition and/or flaming time, flame spread rate, burn length or temperature.

Smoke refers to the light or visibility obscuring nature of the sooty and condensable products of combustion. The percentage transmission of a collimated beam of light is the usual method of measuring smoke density.

Toxicity includes the incapacitating and lethal nature of the products of combustion. The classical means of measuring toxicity is by, for example, what is called an $LD_{50}$ (the dose or weight of a combusted material that is lethal to 50 percent of an exposed population of animals). Other more contemporary measurements include time of incapacitation, which some people believe is related to escape potential, and the amounts of toxic and irritant gases produced during combustion. Accurate gas measurements involve complex sampling and analytical procedures.

In summary, standardized flammability and smoke tests are relatively simple and can be performed by properly trained and experienced technicians. Toxicity tests on the other hand are far more complex and in an earlier stage of development, and usually require the services of professionals, although some animal tests can be systematized to a level which will allow technicians to perform the experiments.

2.2.1 Objective.

The ultimate objective of the test methodology development task is to determine what test or series of tests, test conditions, and data or scientific treatment of data best relate to the fire hazards of burning cabin materials in a postcrash external fuel fire environment.

2.2.2 Major Activities and Basic Approach.

The major activities under the test methodology development task are as follows:

a. Flammability
b. Smoke
c. Toxicity
d. Combined Hazard Index
e. Correlation Study of Small-Scale Tests with Large-Scale Tests

The basic approach is fairly straightforward. The best state-of-the-art test methods for flammability, smoke, toxicity, and combined hazards which appear to relate to postcrash cabin fire survivability will be developed and/or made available. Significant R&D is required in all areas with the possible exception of smoke (obscuration). These small-scale test results will be statistically correlated with the fire hazards and survivability measured during large-scale tests with the design fire derived under section 2.1.1.4. The statistical correlation study will determine what test or series of tests, test conditions, and data or scientific treatment of data provide the best relationship with fire hazards and survivability. Some data, which may allow for simplification of this study, for example, as the result of the preponderance of certain hazards or conditions, may be forthcoming from the planned C-133 "typical" wide-body material tests (section 2.1.1.3).

2.2.3 Flammability.

2.2.3.1 Current Status.

The Technical Center has operational a number of widely-used test methods that will be evaluated under the small-scale/large-scale test correlation study (see section 2.2.7). These tests include the vertical Bunsen burner test prescribed in FAR 25.853, ASTM E-162 Radiant Panel test, thermogravimetric analyzer (TGA), ASTM D-2863 Limiting Oxygen Index (LOI) test, and OSU test chamber. A recently published report studied the relationship between these five flammability tests by comparing data obtained for 20 aircraft materials (reference 18). Except for heat release between the radiant panel test and OSU test chamber, there was very little correlation between the various tests.

The lack of correlation between flammability tests, as exemplified in the above study, has led many test organizations to seek more meaningful and realistic test methods. The OSU test chamber seems to fit into this category for the following reasons: heat and smoke emission rates are measured, these measurements are recorded with time, sample exposure radiation level can be varied, and samples can be tested in either a horizontal or vertical orientation. ASTM is attempting to standardize the OSU test chamber, and the Technical Center is currently participating in round-robin studies sponsored by ASTM Task Group E-5.21.30, Release Rate Test Methods.

The remaining current work is a contractual study at FMRC to pressure model flame spread across a ceiling material. This is a follow-on study to FMRC's earlier work on vertical flame spread (reference 17). The current pressure modeling work is scheduled for completion in September 1980.

2.2.3.2 Future Studies.

The OSU test chamber was recognized by the SAFER Compartment Interior Materials Technical Group as the most meaningful, realistic, small-scale test available with regard to testing materials for cabin fire hazards. This technical group recommended the development and evaluation of the OSU chamber as a test method for combined flammability, smoke, and gas criteria. The Technical Center will begin development of the OSU chamber for this purpose in mid-1980.

The interior materials technical group recommended retention of the vertical Bunsen burner test as well as its modification for materials that melt away from the ignition flame. It is desirable, if possible, to make this test more severe and thus more restrictive of materials. This can be readily accomplished by conducting the test under elevated chamber air temperatures. Materials which "self-extinguish" at ambient temperatures may not at higher temperatures. A contract will be let to modify the vertical test to allow for testing at elevated temperatures. A series of aircraft materials will be evaluated at various elevated temperatures; the data will be correlated with OSU test chamber and radiant panel results. The contract will be awarded in the first quarter of FY-81 and will extend for a period of 6 months.

There are two important aspects of the flammability problem that must be better understood and eventually integrated into future fire test methods and criteria: flame spread rate and flashover (or flash fire). Flame spread rate is a measurement of the velocity of a flame front across the surface of a material. Flashover is the sudden and very rapid fire involvement of an enclosure, especially across its ceiling and upper portion. (Flash fire usually refers to the ignition and propagation of a flame front through a medium of combustible gases at a concentration within the mixture flammability limits.)

2.2.3.2.1 Flame Spread Rate.

It is generally recognized that an accurate and realistic measurement of flame spread rate cannot be provided at this time by existing fire test methods. Flame spread rate is a crucial measurement implicitly related to fire hazard because it provides an indication of the rapidity by which a fire will spread and, therefore, the quantity and area of materials that will be producing hazardous combustion products. The most scientific method of relating small-scale flame spread measurements with large-scale flame spread measurements is through the pressure modeling approach (reference 17). This technique has been validated for horizontally (floor-like) and vertically oriented materials and is now being validated at FMRC under an FAA contract (section 2.1.2) for horizontal ceiling materials. The results of the pressure modeling work at FMRC and in the future at the Technical Center will be used to design and evaluate a new type of test for measuring flame spread rates.

2.2.3.2.2 Flashover.

The occurrence of a flashover corresponds to that point in time when human survival is no longer possible. Flashover is accompanied by significant increases in heat, smoke, and toxic gas concentrations beyond survivable proportions. A major study, perhaps extending over a period of several years, is required to:

a. Determine the probability and conditions needed for the occurrence of flashover (e.g., smoldering, ventilation, or oxygen-controlled flaming combustion, etc.).

b. Determine if a small-scale test, similar to that developed at the National Bureau of Standards (NBS) by partial FAA funding (reference 19), adequately characterizes the propensity of aircraft materials to flashover under postcrash cabin fire conditions.

The flashover effort will be prioritized and developed after the importance of flashover, in comparison to other fire hazards, can be established for the postcrash cabin fire environment (section 2.1.1.3).

2.2.4 Smoke.

There are no major efforts currently envisioned for developing new smoke test methods for or conducting smoke emission studies on cabin materials. The Technical Center operates a standard NBS smoke chamber, a modified NBS smoke chamber with high flux heater and sample weight loss monitor, and the OSU test chamber. These test methods are available and believed to be adequate for characterizing the smoke emission characteristics of cabin materials during planned small-scale/large-scale test correlation studies (section 2.2.7). A recently published report demonstrates the importance of heat flux level and the presence or not of a flaming ignition source on smoke density for a series of cabin materials (reference 20).

2.2.5 Toxicity.

How can the toxic threat during a postcrash cabin fire be minimized by the screening selection of interior materials using a small-scale test(s) procedure? What is the toxic threat and how can it be measured in the laboratory? What is an appropriate small-scale test(s) procedure? These questions are the driving functions behind research in combustion toxicology today.

There are no standardized small-scale toxicity test methods, although various tests have been developed and numerous materials evaluated over the past 10 years. A list of recommended research areas requiring long-term activity was compiled by the SAFER Ad Hoc Committee on Toxicology and implies that many fundamental problems still exist despite the existence of various tests developed by many different organizations (reference 21).

2.2.5.1 Current Status.

FAA research and testing in combustion toxicology and toxic gas analysis has been conducted at both CAMI and the Technical Center. Several years ago, a cooperative program between CAMI and the Technical Center was completed. This program involved the development of a combustion tube furnace (CTF) test method, which was used to

evaluate 75 aircraft cabin materials on the basis of animal toxicity at CAMI (reference 22) and the measured yields of 9 specific toxic gases at the Technical Center (reference 23). A subsequent report prepared at the Technical Center described for this study the corelation of animal toxicity with toxic gas yields (reference 24). On a statistical basis, this report demonstrated that the animal toxicity could be described almost entirely by the yields of several systemic poisons (CO, HCN, and $H_2S$), but that the overall effect of the irritant gases measured was actually to decrease toxicity (i.e., prolong time of incapacitation apparently by inhibiting breathing and thereby reducing the intake of systemic toxicants). Current primary activity at CAMI has until recently been centered about the development of an NBS toxicity test protocol, and at the Technical Center it is the measurement of toxic gases within the C-133 full-scale cabin fire environment.

#### 2.2.5.2 Future Studies.

The resources at CAMI and the Technical Center will be utilized to develop a state-of-the-art toxicity test for application to aircraft cabin fires. CAMI will have the primary responsibility for test method development which will begin upon completion of their recently initiated irritant gases study (section 2.3.2.2.2). It is important that the FAA have quantitative data with regard to similarities and differences between the NBS and FAA toxicity test protocols. The Technical Center will have the responsibility for development of the OSU chamber as a multihazard test method, including toxic gases analyses and possibly animal toxicity measurements. Thus, three test methods will be available for the correlation study: an FAA toxicity test method, the NBS toxicity test protocol, and the OSU multihazard test chamber.

There are two important modifications which must be made to the CTF test method if it is to become the basis for an FAA toxicity test:

a. Incorporation of unidirectional heating.
b. Evaluation of irritant gases.

#### 2.2.5.2.1 Unidirectional Heating.

During a survivable postcrash cabin fire, in most cases the interior materials remain in place for the short time interval when escape is possible. Except for edge effects, it is the surface materials alone which are initially involved in fire or pyrolysis, and the sub-surface materials only begin to decompose as heat is transferred inward and as the surface materials become consumed. The current method of exposure in the CTF consists of emersing the entire sample in heat, thus allowing the sample to be heated from all directions. This method does not realistically expose multi-layered materials, which comprise a significant portion of the cabin interior; e.g., sidewall and ceiling panels, laminates, and flooring, to a unidirectional heating.

#### 2.2.5.2.2 Irritant Gases.

The motor-driven rotating wheel animal exposure system used in the CTF for determining times of incapacitation and death does not appear to be an appropriate model for gauging the human hazards of irritant gases (reference 24). The following interior materials used in significant quantities in some commercial aircraft are examples of materials known to produce when burned the noted irritant gases:

a. Polyvinyl Fluoride - hydrogen fluoride (HF)
b. Polyvinyl chloride - hydrogen chloride (HCl)
c. Wool - sulfur dioxide ($SO_2$)
d. Urethanes - organic acids (aldehydes)

What effect these irritant gases have on human escape during a postcrash cabin fire is not known and is very controversial. Adaptations must be made to the CTF to include the effects of irritant gases. The easiest approach appears to be to measure the gases of concern and use the human tolerance limits to be established by planned research (section 2.3.2.2.1) to calculate the hazard. Another approach which may prove to be impractical or expensive is to develop an animal model which has a sensitivity to irritants similar to that of humans. Additional planning is required to more completely define this undertaking.

### 2.2.5.2.3 Additional Studies.

A number of additional studies supportive of current, in-house activities have been identified:

a. Flaming Combustion - There is evidence which indicated that materials may not be toxic to any significance under conditions of open flame. Much of this evidence is in the form of small-scale tests (e.g., the NBS smoke chamber, the laboratory animal exposure chamber at the Technical Center, etc.), although some large-scale data are in existence (reference 25). A study will be undertaken to conduct open flaming and pyrolysis tests on typical cabin materials in order to measure the toxicity and toxic gas emissions over a range of sizes, eventually reaching those of a real cabin. Tests will be conducted with and without forced airflow across the surface of the sample. The purpose of this study will be to determine the modes of combustion that are required in the CTF test method in addition to the presently-used oxidative pyrolysis condition.

b. Hydrogen Cyanide (HCN) and Hydrogen Sulfide ($H_2S$) Analysis - A recently developed gas chromatographic (GC) method of analysis for HCN in samples collected in Tenax® tubes is currently being used in the C-133 test article. No method of $H_2S$ analysis is available. A contractual study will be awarded to develop continuous or semi-continuous methods of analysis for HCN and $H_2S$ for utilization in the full-scale C-133 environment. The importance of these measurements overrides any consideration of duplication of effort which may evolve if the GC HCN procedure proves sucessful.

## 2.2.6 Combined Hazard Index.

### 2.2.6.1 Objective.

The objective is to develop a small-scale test methodology for determining a single index which combines the hazards of flammability, smoke, and toxicity for a material under postcrash cabin fire conditions.

### 2.2.6.2 Background.

The FAA's issuance of three separate proposed regulatory notices for flammability, smoke, and toxicity was criticized as a "piecemeal" attempt at improving cabin fire safety (reference 26). It was argued that these factors were interrelated, and

that any new regulation pertaining to any one factor would require expensive design changes at its adoption and also again on each occasion that new regulations went into effect for the other factors. With this criticism in mind, the FAA issued a request for proposal (RFP) for the design, development, and verification of a CHI test methodology.

The recipient of the contract was the Douglas Aircraft Company (DAC). The contractual study has been in existence for several years and is near completion.

2.2.6.3 Technical Approach.

The approach selected by DAC was to utilize a single test method—the OSU test chamber—to measure heat, smoke and toxic gas emission rates as a function of time. A mathematical enclosure fire model computes the distribution of hazards within DAC's Cabin Fire Simulator (CFS), which is their large-scale cabin fire test article. The hazards are combined by computing their contribution to the theoretical remaining escape time at some selected CFS location. It is assumed that the various hazards have an additive effect on escape time, and acute escape time limits for the various hazards are based primarily on extrapolated data. The OSU test method data acquisition and the mathematical model are computerized, which helps make the computation of a CHI an automated process. The accuracy of the OSU/mathematical model predictions is determined by comparison with test data obtained in the CFS. The planned completion date of this study is December 1980.

2.2.7 Correlation of Small-Scale and Large-Scale Tests.

Perhaps the most difficult and also most important undertaking in the fire safety program plan is a planned study to correlate small-scale and large-scale test results. This study will commence upon completion of the development of various small-scale tests, as described in sections 2.2.3 to 2.2.6. A large number of small-scale tests will be examined during the correlation study, including the vertical Bunsen burner test, (FAR 25.853) and other widely used flammability tests, standardized NBS smoke chamber, modified NBS smoke chamber (variable high flux heater), combustion tube furnace, OSU test chamber for multiple hazard measurements and the CHI methodology.

Two important aspects of the correlation study must be developed:

a. Statistical design of the study.
b. Design of the large-scale cabin fire tests.

With regard to the former, consultants will be obtained to assist in statistical experimental design. All previous small-scale/large-scale test correlation work must be reviewed and studied in order to assure a logical FAA study. It is believed that some of the correlation work exists as unpublished industry reports. In order to extract this potentially important information, a study will be undertaken to canvas the fire research community for correlation studies. The contract will be awarded to an organization with known contacts throughout industry, government, and academia. As now envisioned, the contractual study will:

a. Identify, categorize, and evaluate all known small-scale/large-scale test correlation studies.

b. Recommend the most logical correlation approach, based on past work, for the postcrash cabin fire safety problem. It is mandatory that the large-scale tests be conducted with the design fire derived under section 2.1.1.4.

c. Evaluate the role of physical fire modeling in bridging the gap between small-scale tests and large-scale tests.

d. Evaluate and recommend instrumentation and measurements used at the Technical Center in small-scale, large-scale, and model tests.

### 2.2.8 Major Milestones.

Major milestone estimates are grouped in figure 6. It should be emphasized that the milestone schedule shown in figure 6 is an estimate of work schedules based on current knowledge. More accurate milestones will evolve as detailed project plans and contractual work statements are developed.

## 2.3 SURVIVAL AND EVACUATION.

FAA regulations require that the design of a transport cabin allows for the evacuation of a full complement of passengers through one-half of the emergency exit openings within 90 seconds. The actual evacuation time in a real accident is usually greater than the 90-second requirement (FAR 25.803) because of psychological factors such as panic, inaction, and group behavior and various fire-related hazards. The major fire-related hazards are as follows:

a. Smoke and numerous irritant gases, causing loss of visibility and eye irritation and lachrymation.

b. Heat, causing thermal stress.

c. Oxygen depletion, posing a life hazard in a ventilation restricted environment.

d. Numerous toxic and irritant gases, posing a life hazard.

In order to understand the nature of the postcrash cabin fire problem and the role of cabin materials, it is essential that quantitative human tolerance limits for acute exposure to each of these hazards and hazard elements be available.

Survival in an environment comprised of the various hazards identified above is strongly time-dependent (classical dose-response relationship) and, therefore, closely linked with evacuation. The overriding consideration in aircraft cabin fire safety is the provision for the most rapid evacuation rate of passengers and crew members. Emergency lighting systems in a smoke-filled cabin and heat resistant evacuation slides are projects within this program plan that have a direct bearing on evacuation. Also, the usage of protective breathing devices for passengers and crew members is a concept that appears to merit reconsideration.

### 2.3.1 Major Activities.

The major activities under the survival and evacuation task are as follows:

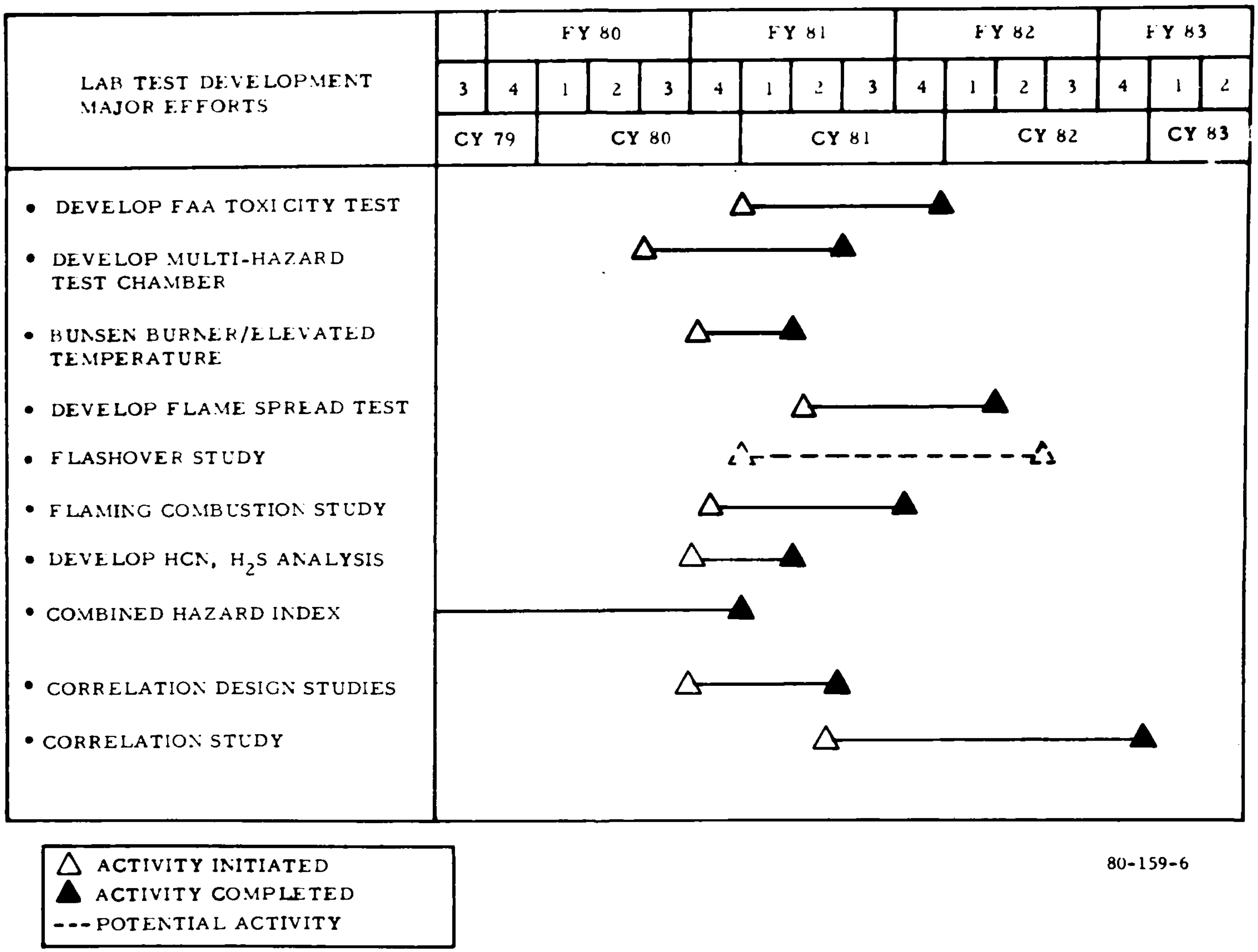


FIGURE 6. LABORATORY TEST DEVELOPMENT MILESTONES

a. Human Survival Limitations
b. Emergency Lighting
c. Evacuation Slides
d. Protective Breathing Devices

2.3.2 Human Survival Limitations.

2.3.2.1 Current Status.

FAA experimental studies related to human survival are performed at CAMI. In response to the R&D request entitled "Physiological Criteria for Humans Exposed to Cabin Fires," CAMI has derived a temperature-time tolerance limit; developed equations for predicting incapacitation times, individually or in combination, for the systemic toxic gases CO, HCN and $H_2S$; and summarized human tolerance limits to oxygen depletion. However, the incapacitating effects of irritant gases such as HF, HCl, $SO_2$, etc., were not readily assessible from information within the literature. Conclusive information was also found to be wanting for the effect on evacuation performance of smoke density from a visibility obscuration consideration.

2.3.2.2 Future Studies.

2.3.2.2.1 Escape Impairment In Nonhuman Primates Exposed To Irritant Gases.

A contractual study will be undertaken to determine the potential of representative irritant gases to impair human escape from a fire environment. It will be necessary to develop and utilize an animal model and behavioral testing methodology which will provide information that can be extrapolated to man. This difficult requirement can best be satisfied using a nonhuman primate, possibly a baboon. A behavioral task will be designed to measure the animal's escape impairment in a environment containing a measured concentration of a single irritant gas in air. At least one gas from each of the following four families of irritant gases will be studied: halogen acid gases, organic aldehydes, inorganic acid anhydrides, and organic acids. The study will establish a dose-response relationship and the threshold concentration for escape impairment by the gas.

2.3.2.2.2 Incapacitation And Escape Impairment In Rats Exposed To Irritant Gases.

Materials are most commonly evaluated in the laboratory for combustion toxicology using one of several rodent behavoiral tasks. Disagreement exists as to the relevance of either of the tasks to escape impairment or to their responsiveness to irritant gas exposure. In conjunction with the planned study using nonhuman primates (section 2.3.2.2.1), the opportunity exists for addressing these critical issues. Therefore, studies will be undertaken at CAMI and possibly an academic institution, to examine the behavoir of rats exposed to various single irritant gases in air, as in section 2.3.2.2.1. The behavioral tasks which will be analyzed will be incapacitation (motor-driven rotating wheel) and escape (shuttle box arrangement). Thus, comparisons will be possible between escape and incapacitation in rodents, and, for escape, between nonhuman primates and rodents.

2.3.2.2.3 Human Survival Model.

Full-scale fire tests such as those conducted in the C-133 test article provide data on the variation of temperature and gas concentrations with time. This

data are widely interpretative because of the absence of a theoretical human survival model. A study is required to develop a state-of-the-art human survival model that would periodically be upgraded as more data, such as from the two studies outlined above, becomes available. The model should provide for the best treatment available of the following:

a. Vertical thermal profiles (stratification).
b. Time-dependent heat and gas profiles.
c. Combinations of heat, gases and oxygen depletion.

Although hypothetical in nature, the model would provide for consistent comparisons between large groups of data in terms of a single and most relevant parameter—human survival—rather than "abstract" measurements of temperature and gas concentrations. It is estimated that the initial study can be completed over a period of 6 to 9 months.

2.3.2.2.4 Evacuation in Smoke Environment.

The presence of smoke will produce a loss in visual acuity and impairment in vision. These effects in a postcrash cabin fire will prolong the time required to evacuate the aircraft. A study is required to determine the relationship between evacuation rate and smoke optical density. This work will be conducted in a simulated aircraft cabin with human volunteers subjected to a theatrical smoke. The benefit of advanced emergency lighting systems under the conditions of "dense smoke," both determined in section 2.3.3, will also be examined. The duration of this study is estimated to be approximately 9 to 12 months.

2.3.2.2.5 Combined Effect of Heat and Toxic Gases.

In a postcrash cabin fire involving burning fuel, C-133 test data indicate that heat may be a significant factor affecting survivability (reference 12). What then is the combined effect of heat and toxic gases produced by burning cabin materials on survival? For lack of reliable data indicating otherwise, it is now assumed that the effect of heat and toxic gases is additive. This assumption must be verified or, if the data so indicates, modified. A study is visualized that will examine the effect of heat and CO, and of heat and HCN, on survival. Because small animals are easily heat stressed compared to humans, it will be necessary to use primates, possibly baboons, for this study. If this is the case, then the study will be initiated upon completion of the previous study on escape impairment of irritant gases. Approximately 9 to 12 months is required to study the combined effects of heat and toxic gases.

2.3.3 Emergency Lighting.

2.3.3.1 Objective.

The objective of this project is to evaluate emergency exit signs and lights that will enhance the evacuation rate of airline occupants from the smoke-filled cabin environment created by a survivable postcrash cabin fire.

2.3.3.2 Background.

A National Transportation Safety Board (NTSB) study examined a number of survivable accidents in which evacuation was carried out at night or in the presence of smoke

(reference 27). It was concluded that inadequate cabin illumination hindered the ability of passengers to move through the cabin and locate emergency exits. Numerous advanced emergency lighting and exit sign concepts have been evaluated at CAMI using white theatrical smoke within a cabin simulator. Subsequently, it became desirable to evaluate these advanced concepts under realistic black smoke conditions more typical of a post-crash cabin fire, and to define a "dense smoke" concentration for their evaluation.

2.3.3.3 Technical Approach.

Test have been and are currently being conducted in the C-133 test article. Basically, candidate advanced emergency lighting and exits are monitored with photometric instrumentation and observed from a viewing booth adjacent to the C-133. Smoke meters continually record the optical density of smoke. Based on tests conducted with fuel fire smoke only, it was apparent that emergency lighting and signs should be lowered from their present upper cabin location because of the significant stratification of smoke (reference 28). Present efforts include the following:

a. Simultaneously comparing the visibility of "armrest" lights, electrically-powered and self-powered floor-mounted aisle contour lighting, exit signs at various vertical locations and "360°" lighting around exit doors.

b. Conducting these comparisons in smoke produced by the combination of burning fuel and interior materials.

c. Defining a "dense smoke" condition for evaluating emergency lighting and exits, which is the maximum smoke density compatible with human survival, as measured in a full-scale (C-133) cabin fire environment (see 2.1.1.3).

d. Performing evacuation experiments using human subjects in a cabin simulator at CAMI to determine the difference in evacuation rate in an artificial smoke environment between conventional and seat-mounted emergency lighting. This work is scheduled for completion by the end of FY-80.

2.3.4 Evacuation Slides.

2.3.4.1 Objective.

The primary objectives of this project are as follows:

a. Design and develop a laboratory test method relevant to full-scale postcrash fire conditions and suitable for materials qualification testing in airworthiness certification.

b. Develop a practical and lightweight coating for retrofitting inservice evacuation slides that will significantly increase their resistance to thermal radiation.

c. Examine and foster the development of advanced materials that are resistant to thermal radiation and suitable for use in the fabrication of evacuation slides.

d. Determine heat resistance acceptance criteria for slide materials.

2.3.4.2 Background.

The NTSB investigation of the Continental DC-10 accident at Los Angeles indicated that the slide/raft at 1R failed because of radiant heat from the fuel fire (reference 29). The early indication of this occurrence prompted the Technical Center to conduct a preliminary assessment of the fire protection characteristics of various escape slide materials (reference 30). The outstanding finding indicated in both small-scale and outdoor tests was that a substantial increase in the inflation time of pressurized slide fabric samples was provided by a thin coating of aluminum paint. However, it was recommended that a more comprehensive program be conducted to collect the additional technical data necessary to support possible future rulemaking related to testing slide materials exposed to thermal radiation.

2.3.4.3 Technical Approach.

The project effort is divided into four tasks:

2.3.4.3.1 Task 1.

A laboratory test suitable for regulatory purposes will be designed and developed. An important feature of the new test method will be an expedient and leak-free means of pressurizing the sample. Additional numbers of the test method will be fabricated at the Technical Center and delivered to major airframe and slide manufacturers to allow for the consistent evaluation of new materials and coatings.

2.3.4.3.2 Task 2.

A contract has been awarded to a slide manufacturer to develop a reflective coating for possibly retrofitting inservice slides and slide/rafts. The contractor will select an optimum coating based on an examination of radiative heat resistance, weight, methods of application and integrity after long-term creasing when packed. The contractor will determine time and cost of a fleet retrofit.

2.3.4.3.3 Task 3.

In order to encourage the use of superior materials in the manufacture of slides for future transports, the slide manufacturers and material suppliers will be solicited for candidate advance materials for evaluation at the Technical Center. Several real slides constructed of the most promising materials will be evaluated under full-scale pool fire conditions.

2.3.4.3.4 Task 4.

At various stages during the project, real evacuation slides or slide/rafts will be subjected to the thermal radiation produced by a large fuel fire. The initial tests will involve testing a series of inservice slides to establish the failure mode under the most realistic conditions possible and to provide full-scale data for comparison with laboratory data from the new test method. Later, real slides protected with the optimum coating selected under Task 2 will be tested to demonstrate the effectiveness of the coating in prolonging the usable time of the slide. Finally, similar tests will be conducted on slides fabricated from the best

advanced material. Based on laboratory and full-scale examinations of various evacuation slide materials, heat resistance acceptance criteria that are both beneficial and practical will be determined.

This project is scheduled for completion in September 1980.

2.3.5 Protective Breathing Devices.

In recent years there have been significant advancements made in the design of protective breathing devices for personnel protection. For example, the latest designs are lighter and less bulky than some of the earlier devices, and incorporation of a small oxygen cannister in some designs provides a substantial increase in their usable breathing time. These advancements in light of the difficult technical problems that must still be overcome with regard to understanding and improving cabin fire safety indicate that the use of protective breathing devices for airline occupant protection deserves reconsideration. A comprehensive study will be undertaken to reconsider the use of protective breathing devices as prioritized below:

a. Protective breathing devices for crew member use only.

1. Evaluating the benefits of recent advancements.

2. Examining the feasibility of using protective breathing devices for both in-flight and postcrash fire protection, and for the replacement of the present oxygen system used for depressurization protection.

3. Examining the effects of different facial sizes (male versus female) on equipment efficiency.

4. Establishing airline operational requirements.

b. Protective breathing devices for passenger use.

1. Evaluating the benefits of recent advancements.

2. Examining the feasibility of using protective breathing devices for both in-flight and postcrash fire protection, and for the replacement of the present oxygen system used for depressurization protection.

Depending on the results of b-1 and b-2, then proceed with:

3. Determining the effect that donning a protective breathing device has on evacuation time.

4. Determining the educational requirements to assure maximum efficiency and effectiveness.

5. Examining for possible passenger resistance to the use of protective breathing devices.

It is estimated that this comprehensive study will require approximately 18 months for completion.

### 2.3.6 Human Factors.

Human factors have been proven to have an important bearing on escape from fire. Aside from the well known physical advantages of age, sex, and health, awareness of possible dangers and readiness to take immediate action increase the probability of escape of potential fire victims. The adequacy and effectiveness of preflight briefings relative to postcrash cabin fire safety is open to question. Based on a cursory analysis of human factors in cabin fire safety, the following tentative areas of study have been identified:

a. Educational requirements for passenger awareness.

b. Crewmember training effectiveness for firefighting and evacuation.

c. Comprehensive review of adequacy of current evacuation philosophy by regulation and aircraft design.

## 2.4 FIRE MANAGEMENT AND SUPPRESSION.

In building construction, fire protection is achieved by the application of fire management and suppression concepts. For example, ceiling mounted water sprinkler systems automatically suppress fires; firewalls localize and contain fires until controlled by firefighters; fire escapes provide protected avenues for escape; and fire alarms automatically detect the existence of fires. Similar concepts are utilized in transport aircraft for <u>in-flight</u> fire protection. Fire detection systems mounted in the engine nacelle and APU's provide for the detection of an engine or APU fire; Halon 1301 or other agents are used for extinguishment. Some cargo compartments are protected by fire detectors, suppression systems, and airflow shutoff devices. The lavatory waste paper disposal compartment is fire hardened and, in some instances, protected with a small self-actuated, Halon 1301 bottle. Portable fire extinguishers operated by crew members can be used to extinguish small, in-flight fires. The fundamental question is whether fire management and suppression concepts can be applied to the design of a cabin for the improvement of <u>postcrash</u> cabin fire safety.

### 2.4.1 Current Status.

The most recent large-scale experimental studies related to onboard cabin fire protection were performed at the Technical Center in the areas of compartmentation and Halon 1301 fire suppression. An examination of various compartmentation concepts, including class dividers, curtains and headliners, demonstrated that the effectiveness of the concept depended on the degree of airflow blockage between sections. Also, an effective compartmentation concept sometimes had an adverse effect on the hazard level in both the fire and protected areas (reference 31). Based on this limited study, the conclusion was that compartmentation was not a promising approach because of the usually nonexistent or questionable benefit, and unknown effect on evacuation. In a later study, it was demonstrated that an onboard Halon 1301 system could effectively and safely extinguish fires wholly contained within the cabin environment. However, this system displayed limited effectiveness and was not safe against an external fuel fire adjacent to a door opening because of significant agent decomposition caused by the incompletely extinguished fuel fire flames (reference 32). Thus, it appeared that the application of Halon 1301 could have a counterproductive effect on postcrash cabin fire

safety. The Technical Center in-house activity in cabin fire management and suppression temporarily ceased about 3 years ago upon the completion of these projects.

### 2.4.2 Future Studies.

The complexity of the postcrash cabin fire safety problem and the potential loss of life demands that the viability of cabin fire management and suppression be thoroughly examined. A three-phase study is planned.

#### 2.4.2.1 Phase I.

This will be a contractual study to examine the feasibility of all known systems and concepts. These include but are not limited to:

a. Fuselage and window burnthrough resistance.
b. Door hardening.
c. Smoke ventilation.
d. Water fog protection.
e. Advanced fire extinguishing agents.
f. Compartmentation concepts compatible with rapid evacuation.

Each system or concept will fall into any one of three categories. First, the cost/benefit ratio will be estimated for those systems or concepts which appear feasible and beneficial. Second, those systems or concepts which are not feasible or have an extremely poor cost/benefit ratio will be identified as such with supportive documentation. Third, those systems or concepts will be identified which appear promising but require an experimental effort to determine feasibility or estimate cost/benefit. For those systems or concepts falling within the third category, the contractor will identify in detail the nature of the experimental work required to resolve any uncertainties. An estimate will be made of the probability of "success" for each concept or system. A final report will exhaustively analyze each system or concept taken under consideration and in detail describe the logic and analyses employed during their categorization.

#### 2.4.2.2 Phase II.

This phase of the study will be an experimental study to determine the feasibility and cost/benefit of those promising concepts identified in the third category under phase I. The extent of the study as indicated in phase I and in-house commitments to other projects will dictate whether this work is performed in-house or by contract. All feasible systems and concepts will be rated in terms of estimated cost/benefit ratio.

#### 2.4.2.3 Phase III.

The third and final phase will be a study to design the best rated system(s) for installation in a real airplane. Emphasis will be placed on gathering hard data on initial and recurring costs. An accurate cost/benefit value for the best rated fire protection system(s) will be determined for comparison with cost/benefit values for advanced material systems (see section 2.1.1.5).

2.4.2.4 Milestones.

The following are estimates for the duration of each phase of the study:

a. Phase I - 6 months
b. Phase II - 12 to 18 months
c. Phase III - 9 to 12 months

2.4.3 Other Fire Safety Areas.

The aircraft systems fire safety program plan is dedicated to the improvement of postcrash cabin fire safety. The knowledge and expertise within the program is transferable to other fire safety areas which may warrant attention in the future. Some examples of these areas are the following:

a. Hazards related to the emergency oxygen system.
b. Fires originating in the galley.
c. Cargo compartment fire detection and control.
d. Electrical fires.
e. Fires originating in the lavatory.
f. Hand-held fire extinguishers (see section 2.4.5).

One potential problem that needs analysis is that of in-flight smoke removal.

2.4.4 In-Flight Smoke Removal.

2.4.4.1 Objective.

The purpose of this project is to determine the adequacy of and, if necessary, upgrade the operational procedures specified in FAR 25.831 for eliminating smoke from the cabin and cockpit during an in-flight fire.

2.4.4.2 Background.

Little public information exists on venting or evacuating smoke during an in-flight fire. Although progress has been made in improved interior materials, there is no basis of assurance that an in-flight cabin or cargo compartment fire can be managed under every circumstance. It is conceivable that passengers could be incapacitated or killed long before the aircraft itself was rendered inoperable from the fire. There are two major questions to be answered. First, can venting procedures be developed for use by the crew to eliminate smoke buildup in flight? Second, can cabin depressurization be used to control the fire itself?

2.4.4.3 Technical Approach.

Existing information on this problem will be surveyed and summarized. Simple models will be fabricated and installed in the Technical Center 5-foot airflow facility. Flaming and smoldering materials will be used to create smoke, and the effect of openings on smoke evacuation will be evaluated.

A surplus aircraft fuselage will be used for depressurization studies. An augmentor attached to a high pressure (1,000 pounds per square inch) air facility

will be used to rapidly depressurize the fuselage while it is on the ground. Load cell data on sample weight will be evaluated for effects of depressurization on buring rate.

It is estimated that this project is of an 18-month duration.

### 2.4.5 Hand-Held Fire Extinguishers.

#### 2.4.5.1 Objective.

The purpose of this project is to update and expand Advisory Circular (AC) 20-42, "Hand Fire Extinguishers in Transport Category Airplanes and Rotorcraft." Requirements for small aircraft will also be included.

#### 2.4.5.2 Background.

Since AC 20-42 was issued in 1965, there have been significant changes in the civil fleet in aircraft cabin size, configuration, materials, and operating environment, all of which bear on fire protection. Over the same period, new service experience has accumulated and there have been new developments in extinguisher agents and design. AC 20-42 is widely used, and experience indicates it should be updated and expanded to increase its usefulness and more effectively cover all aspects of evaluating and selecting hand-held extinguishers.

#### 2.4.5.3 Technical Approach.

A two-phase program is presently being considered. The initial phase will essentially involve a comprehensive literature search and coordination/contact with various user, standards, and manufacturing organizations. The second phase will involve a test program at the Technical Center possibly focusing in on such items as agent firefighting effectiveness, ventilation effects, neat agent concentration requirements, visibility obscuration effects, cabin volume considerations, agent decomposition, and personnel firefighting procedures.

A 15-month effort is scheduled with a completion date of December 1981.

## 2.5 STANDARDS AND IMPROVEMENTS.

### 2.5.1 Risk Analysis.

The ultimate products of the aircraft systems fire safety plan are new regulatory standards for cabin materials that provide an enhancement of postcrash cabin fire safety. Material standards are based on acceptability criteria measured using small-scale tests. In the past, the derivation of acceptability criteria was simply accomplished by somewhat arbitrarily selecting a value that would eliminate materials that were considered "worst actors." For example, FAA proposed smoke density limits eliminated high smoking materials without being too restrictive so as to impose a design burden on the manufacturer. The relative performance method of screening materials used in the past will be replaced by a rational or risk analysis model incorporating cost/benefit analyses and other factors.

2.5.1.1 Future Contractual Study.

Since no precedent exists for rationally developing fire test acceptability criteria for aircraft materials, a contractual study will be awarded to develop the analysis in the form of a computer program. The contract will be awarded in early FY-81 to provide for adequate literature research and consultation necessary to allow for the preparation of a proper work statement. This interim period will also allow for the completion of cabin fire characterization testing in the C-133 and development of modeling and small-scale test technologies, thus providing the contractor with a better grasp of the problem and the workability of various tools having potential application in the analysis. The contractor will consider and apply:

a. Cost/benefit analysis.
b. Experimental or semiempirical approaches to cabin-fire hazard characterization.
c. Survivability and evacuation modeling.
d. Design fire analysis and the probability of other fire scenarios.
e. Safety efficiency (acceptable cost of safety).

Some planning guidance in the development of a risk analysis model will be furnished by the Data Bank development contract, Task 3 (section 2.5.2.3). The study will transpire concurrently with the small-scale/large-scale test correlation study for an estimated period of 18 months.

2.5.2 Data Bank.

The SAFER Technical Group on Compartment Interior Materials recommended the development of a data bank for interior materials. A data bank will help promote the usage of improved materials in cabin interiors and probably create a competitive environment amongst suppliers leading to increased material availability. NASA and FAA will co-fund a study to define the capabilities and the cost of reasonable options for establishing a comprehensive library data base of aircraft materials with particular emphasis on fire, smoke, and toxicity characteristics. This initial effort to define requirements and options is comprised of three tasks.

2.5.2.1 Task 1 - Data Bank User/Supplier Survey.

The contractor will undertake a survey of potential users within the Government and the private sector to determine who the most likely users may be and how they would utilize such a data base. A survey of potential data suppliers will determine the availability and the form of the supplied data. Preliminary data gathering will be initiated to support the theoretical operation of projected libraries.

2.5.2.2 Task 2 - Data Bank Configuration Options.

The contractor will survey commercially available software packages to support the construction and operation of a library system and alternative computer hardware systems. Computer hardware and software support and maintenance requirements will be estimated. Total cost, schedule and service of each option will be used to rank the alternative concepts.

2.5.2.3 Task 3 - Aircraft Materials Performance/Cost Model Development.

The contractor will provide a detailed review of existing models that may be applicable to a total systems approach to aircraft materials research and regulatory analysis.

A 7-month study scheduled for completion in July 1980 is underway. An accurately calculated schedule and budget for the specific library system that will be developed (as well as other options) will be determined during this initial effort. A subsequent effort is needed to actually develop and implement the data bank concept chosen from the various options evolved during the initial study.

2.5.3 Improvements in Specific Usage Categories.

2.5.3.1 Seat Cushions.

2.5.3.1.1 Objective.

The objective of this project is to perform experimental studies to support the protection or replacement of urethane seat cushions.

2.5.3.1.2 Background.

The flammability characteristics of aircraft cabin materials are considered by many to be representative of the best state-of-the-art materials, except for the urethane seat cushions. For many years there were no viable options for the replacement or protection of flexible, lightweight urethane cushions. Although neoprene foam is clearly superior from a flammability viewpoint, substantial weight penalties (estimated at 2,000 pounds for a 275-passenger wide-body aircraft) have precluded its serious consideration. Moreover, neoprene is inherently smokey and produces large quantities of HCl gas when thermally decomposed.

However, recently great strides have been made in the development of fire retardant neoprene barrier concepts and new lightweight, flexible foamed polymers (e.g., ployimides and polyphosphazines). In light of this progress, the SAFER Technical Group on Compartment Interior Materials recommended the aggressive pursuit of urethane seat cushion protection or replacement measures. A major effort in this regard already exists at the NASA Ames Research Center. Near-term, large-scale tests are planned at the Technical Center to evaluate the performance of these new materials/concepts under severe postcrash fire conditions.

2.5.3.1.3 Technical Approach.

The C-133 test article will be used to evaluate full-scale, wide-body seat assemblies constructed of the following cushion materials: neporene, neoprene blocking layer/polyurethane foam, neoprene blocking layer/polyimide foam, and FAR-approved fire retardant polyurethane foam. This preliminary feasibility study will be a cooperative effort between NASA and the FAA. NASA will screen candidate advanced seat cushion materials and barrier concepts, evaluate seat assemblies under in-flight or simulated (low flux radiant heater) postcrash fire conditions, and construct promising seat assemblies for evaluation in the C-133 under postcrash fire conditions. The fire hazards of each modified seat assembly relative to the inservice seat will be measured and compared in order to establish the potential

fire safety benefit. The output of these experiments will be an indication of the most promising foam cushion materials. If warranted, a follow-on study would be needed to optimize the cushion design in terms of maximum safety and minimum weight penalty. The preliminary study will be conducted in the last quarter of FY-80.

#### 2.5.3.2 Windows.

##### 2.5.3.2.1 Objective.

The objective of this project is to perform large-scale experiments to support the replacement of inservice acrylic windows with more fire resistant epoxy windows developed by NASA.

##### 2.5.3.2.2 Background.

Aircraft occupants cannot survive direct exposure to the heat and flames of a large pool fire. However, if the occupants are inside the airplane and the fuselage is intact, then the aircraft structure will protect the passengers for a finite period of time until melting and burnthrough occurs. At a relatively recent wide-body airplane accident, the investigation revealed that the acrylic windows are the least resistant part of the airplane to fuel fire burnthrough (reference 29). Therefore, the replacement of these inservice windows with a more fire resistant design will improve the overall fire burnthrough resistance of wide-body airplanes.

##### 2.5.3.2.3 Technical Approach.

Preliminary comparative tests of acrylic and epoxy/polycarbonate windows were recently completed at the Technical Center using the 1/4-scale fuselage model. A series of large-scale tests are envisioned in a fire hardened DC-7 fuselage previously used to study the behavior of a large pool fire adjacent to a fuselage (reference 33). Inservice acrylic windows and advanced epoxy windows fabricated by NASA will be fastened to the DC-7 fuselage in close proximity to one another. Both window designs will be simultaneously exposed to radiant heat alone during initial experiments. In later experiments the windows will be completely emersed in the flames of a large pool fire. Comparisons between windows will be made in terms of heat transmission, flame penetration, and ignition of interior materials. This project will be initiated in the spring of 1981 and will require approximately a 4-month effort.

#### 2.5.3.3 Blankets, Pillows, and Headrest Covers.

##### 2.5.3.3.1 Objective.

The objective of this project is to determine if flammability regulations similar to those in existence for cabin materials are warranted for airline furnished blankets, pillows, and headrest covers.

##### 2.5.3.3.2 Background.

Current flammability regulations for cabin materials specified in FAR 25.853 are not applicable to airline furnished items such as pillows, blankets, and headrest covers. A recent study utilizing a small-scale fire test method indicated that the flammability characteristics of these items can differ significantly

between some airlines (reference 34). However, for each item at least one sample was found that was "self-extinguishing." The two issues at hand are: Do flammable airline-furnished items pose any foreseeable cabin fire hazard? If this is true, can this hazard be eliminated or minimized by the use of "self-extinguishing" materials?

2.5.3.3.3 Technical Approach.

Seat tests will be conducted in the C-133 or other suitable test article to examine the ignitability of pillows, blankets, and headrest covers. Both in-flight and moderate postcrash fire ignition sources will be examined. For example, it is of interest to determine if a flammable blanket can cause a seat to burst into flames under conditions where the seat by itself would not ignite. Under those ignition scenarios causing seat fires due to the presence of flammable blankets, pillows, and headrest covers, tests will be repeated with "self-extinguishing" versions of these items to deterine if they provide a measurable degree of fire protection. This study will be approximately 4 months in duration.

2.5.4 Major Milestones.

Major effort milestones are graphed in figure 7. An effort entitled "Derive Acceptability Criteria" of 6-month duration is shown. This effort is the determination of small-scale test acceptability criteria for flammability, smoke, and toxicity that will be the basis for a new interior materials regulation.

2.6 LONG TERM STUDIES.

Long term studies beginning in FY-83 are envisioned in two areas: general aviation fire safety and transport fuselage system fire safety.

2.6.1 General Aviation Fire Safety.

General aviation fire safety is primarily an in-flight problem. The following areas need to be addressed:

a. Adequacy of present material flammability regulations (these are much less severe than in transport aircraft).

b. Application of fire detection and suppression (including hand-held and cabin extinguishing systems).

c. Need for and utility of personnel smoke protection devices.

2.6.2 Transport Fuselage System Fire Safety.

Almost the entire program plan over the next 3 to 4 years is devoted to postcrash cabin fire safety because of the practically flawless in-flight fire record (from a fatality consideration) of United States air carriers. In order to assure continuation of this excellent record, the following efforts are proposed:

a. Determination if current flammability standards reflect state-of-the-art technology with regard to fire safety in the lavatory, galley, cargo compartment, electrical systems, and emergency oxygen system.

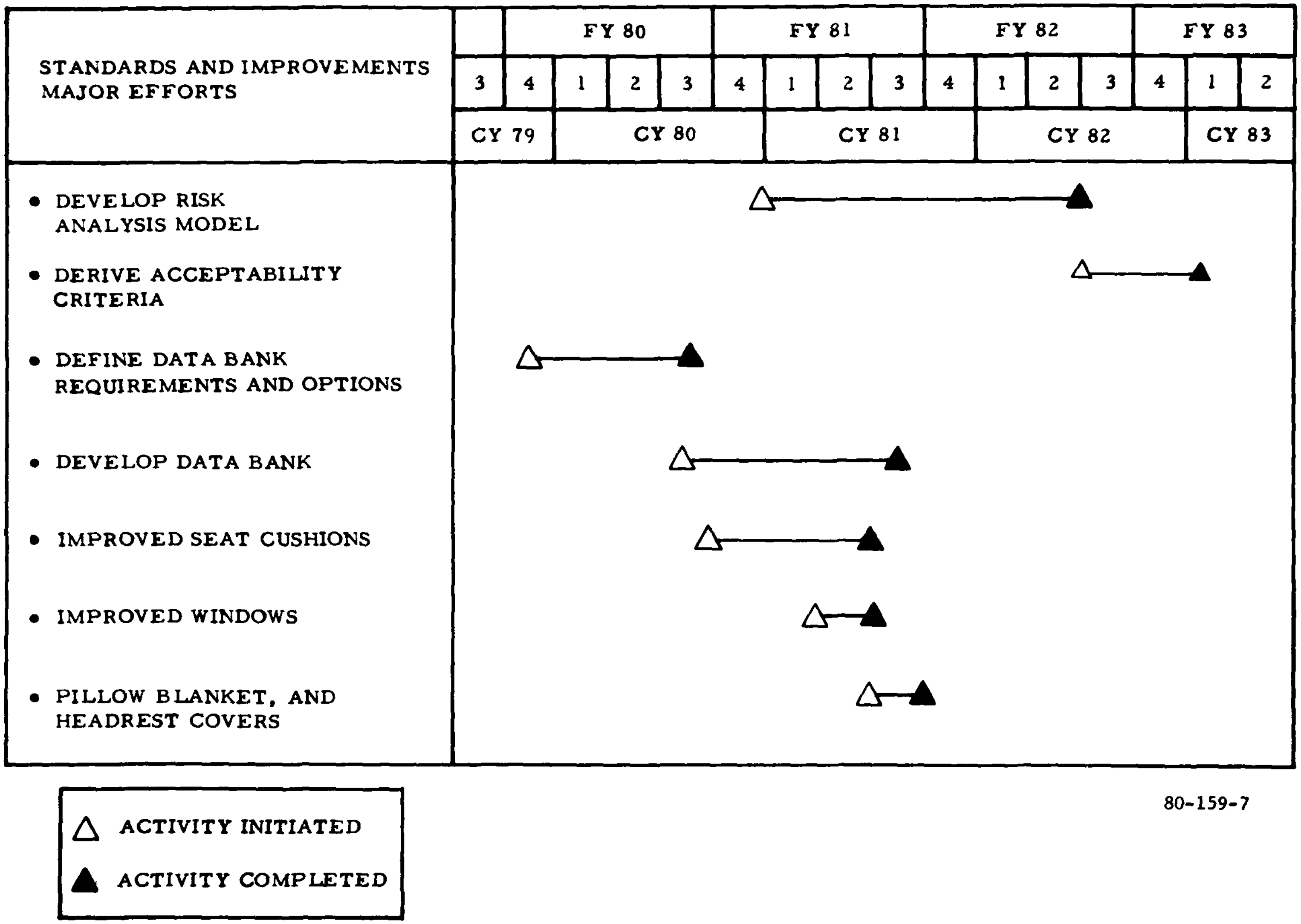


FIGURE 7. STANDARDS AND IMPROVEMENTS MILESTONES

b. Examination of problems associated with increased usage of graphite-reinforced composites (e.g., electrostatic discharge).

c. Determination of adequacy of fuselage design features in impeding fire spread in hidden areas (e.g., behind sidewall paneling or above drop ceiling) and in protecting fuselage flight and control systems from fire related damage.

## 3. FUNDING REQUIREMENTS.

Funds required to provide timely solutions to the cabin fire safety problem are identified in table 1. Allocation of funds by major tasks reflects the emphasis in FY-80 on cabin fire hazard characterization; in subsequent years the monies are distributed fairly evenly between the five major tasks.

TABLE 1. FUNDING REQUIREMENTS—AIRCRAFT CABIN FIRE SAFETY PROGRAM

| Major Tasks | FY-80 | FY-81 (EST) | FY-82 (EST) | FY-83 (EST) | FY-84 (EST) |
|---|---|---|---|---|---|
| 1. Postcrash Cabin Fire Hazards Characterization | 1185 | 875 | 575 | 100 | 0 |
| 2. Laboratory Test Methodology Development | 205 | 425 | 275 | 50 | 0 |
| 3. Survival and Evacuation | 280 | 575 | 450 | 50 | 0 |
| 4. Fire Management and Suppression | 150 | 350 | 200 | 0 | 0 |
| 5. Standards and Improvements | 80 | 375 | 300 | 150 | 0 |
| 6. Long Term Studies | 0 | 0 | 0 | 650 | 1000 |
| Total | 1900 | 2600 | 1800 | 1000 | 1000 |

Note: Numbers Represent Thousand Dollars

## 4. PROGRAM MANAGEMENT.

### 4.1 GENERAL.

The technical management and direction of this program is the responsibility of the Fire Safety Branch, ACT-350, FAA Technical Center. The Fire Safety Branch contains the following four subelements supervised by a "project manager" reporting directly to the Technical Center Program Manager (TPM):

a. Full scale testing

b. Modeling

c. Chemical analysis and toxicity

d. Small-scale flammability and smoke tests; emergency lighting; and evacuation slides.

Each project or activity under the five major tasks described in this program plan is assigned to a project manager, or to the TPM for some contractual efforts, who is then responsible for its accomplishment. Projects or activities related generally to medical or human aspects of cabin fire safety, such as toxicity, human survival limits, smoke hoods, and evacuation in a smoke environment, are usually performed by appropriate groups within the FAA's Civil Aeromedical Institute (CAMI).

### 4.2 COORDINATION WITH NASA.

The Aircraft Cabin Fire Safety Program is complemented by NASA's FIREMEN Program. An agreement as to the responsibilities of each agency is contained within a memorandum of understanding which is updated annually. Coordination is maintained primarily through interagency meetings and informal communications between the responsible individuals within FAA and NASA. Formal review and planning of NASA work is accomplished during meetings of the NASA Inter Center Planning Group on Fire Technology. The major thrust of the NASA program is the development and evaluation of advanced panels, seats, and thermoplastic for aircraft cabin interiors that are superior to inservice materials from the standpoint of flammability, smoke, and toxicity. Significant portions of the program are conducted by the airframe manufacturers. In addition to fire safety performance, advanced materials are examined in terms of functionality, durability, aesthetics, weight, cost, and adaptability to aircraft production methods.

Provisions exist within the program plan to evaluate promising NASA-developed advanced materials under full-scale (e.g., C-133) test conditions (sections.2.1.1.5, 2.5.3.1, and 2.5.3.2.) Other cooperative efforts include the development of a data bank for interior materials (section 2.5.2) and the conduct of fire tests in the NASA 737 test bed to validate on a preliminary basis the DACFIR model (section 2.1.2.3).

## 4.3 PARTICIPATION ON TECHNICAL OR ADVISORY COMMITTEES.

Individuals working in the program participate on various fire safety and aircraft safety technical committees to assure maximum integration and benefit from related activities. These committees include the following:

a. NBS Ad Hoc Committee on Mathematical Fire Modeling

b. ASTM E-5 Committee on Fire Standards

c. NFPA Aviation Committee

d. SAE S-9 Cabin Safety Provisions

e. SAE A-20C Aircraft Lighting, Interior

The FAA program will interface closely with the work and recommendations of the SAFER Advisory Committee.

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